TROPICAL PROPAGATION RESEARCH

Semiannual Report Number 10

1 July 1967 - 31 December 1967

Prepared for

U.S. ARMY ELECTRONICS COMMAND

Fort Monmouth, New Jersey

Signal Corps Contract

DA 36-039 SC 90889

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY

Office of Secretary of Defense

ARPA ORDER 371

ATLANTIC RESEARCH

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Jansky & Bailey Engineering Department

of

Atlantic Research Corporation
A Division of The Susquehanna Corporation
Alexandria, Virginia

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Approved by

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ACKNOWLEDGMENT

This extensive radio propagation study program in Thailand has been possible only through the invaluable support of several organizations there. Jansky & Bailey particularly wishes to express its gratitude for the cooperation and assistance received from the Joint Thai - U. S. Military Research and Development Center in conducting the field measurements described in this report.

ABSTRACT

Semiannual Report Number 10 of the Tropical Propagation Research Project contains the results of measurements and analyses done between 30 June and 31 December 1967. The measurements were conducted in a thick rain forest located approximately half-way between the towns of Songkhla and Satun on the southern peninsula of Thailand. Five different sets of data are covered herein: (1) path losses for frequencies from 880 kc/s to 250 Mc/s at 0.1-6.0-mile transmission distances, with antennas located from 0 to 120 feet above ground; (2) path losses for frequencies from 25-250 Mc/s at 0.05-1.5-mile distances. Transmitting antennas vary from ground level to 120-foot elevations, and receiving antennas were at various heights and orientations within 10 feet of the ground; (3) Path losses and foliage attenuation rates for 0.55-10 Gc/s frequencies over 300-foot transmission paths and at antenna elevations from 9 to 99 feet; (4) path losses for 25-400 Mc/s frequencies at distances from 0.01 to 1.5 miles, using 160-foot-high transmitting antennas and 6-foot-high receiving antennas; (5) temperature, rainfall, and humidity data for the period covered by this report. Except for the 880-kc/s transmissions, all tests were conducted at both polarizations. In certain tests, the data has been averaged, or otherwise reduced, and compared with different data from equivalent tests.

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1. INTRODUCTION

The purpose of the Tropical Propagation Research Project is to investigate radio wave propagation in tropical environments. Its research is conducted through field measurement programs in Thailand that are followed up by mathemathical analyses in the United States. This project is sponsored by the Advanced Research Projects Agency of the Department of Defense as part of SEACORE, and is under the technical and contractual direction of the U. S. Army Electronics Command, Fort Monmouth, New Jersey.

Semiannual Report ~~Number~~ 10 describes recent experimental results from the project's second phase of tests. A section of heavy rain forest, identified as Area II in Figure 1.1, is the setting for the present tests. Begun in 1966, the second test phase is providing data to refine and expand conclusions drawn from an initial series of propagation tests. The initial phase of research, lasting from 1962 to 1966, was conducted in a region of medium heavy jungle, (Area I in Figure 1.1). The two other test locations, Areas A and B, that appear in Figure 1.1 are part of the initial research phase and consist of small plots of jungle used for short-range tests with frequencies at 550 Mc/s and above. Area A lies within Area I, and Area B was a section of bamboo growth on the sea coast.

Figure 1.2 has been prepared to outline the scope of the tests that have been conducted so far. Basically the figure shows the distance ranges covered with each test frequency. Inside each frequency-range block are up to three different cross hatchings to indicate tests in the three different tropical environments. A set of numbers within the cross hatching indicates the approximate antenna height range over which measurements were made. Many parameters, besides the ones of frequency, range, height, and environment shown in Figure 1.2, have been investigated. They include polarization, modulation, antenna directivity, time and spatial variation, wind and rain effects, ionospheric reflections, terrain irregularities, and propagation modes.

A full description of the environment and tests in Areas I, A, and B is in Final Report Volume I[1] of this project. The present test location, Area II, lies in an uninhabited, densely vegetated tropical rain forest between the towns of Songkhla and Satun. In order to reduce the logistical support and construction investment for this test facility, the technical personnel reside in the coastal town of Songkhla, daily traveling to and from the test site by air. Initially, a helicopter provided air transport; however, its availability could not be extended beyond the summer of 1967. As a result, it was decided

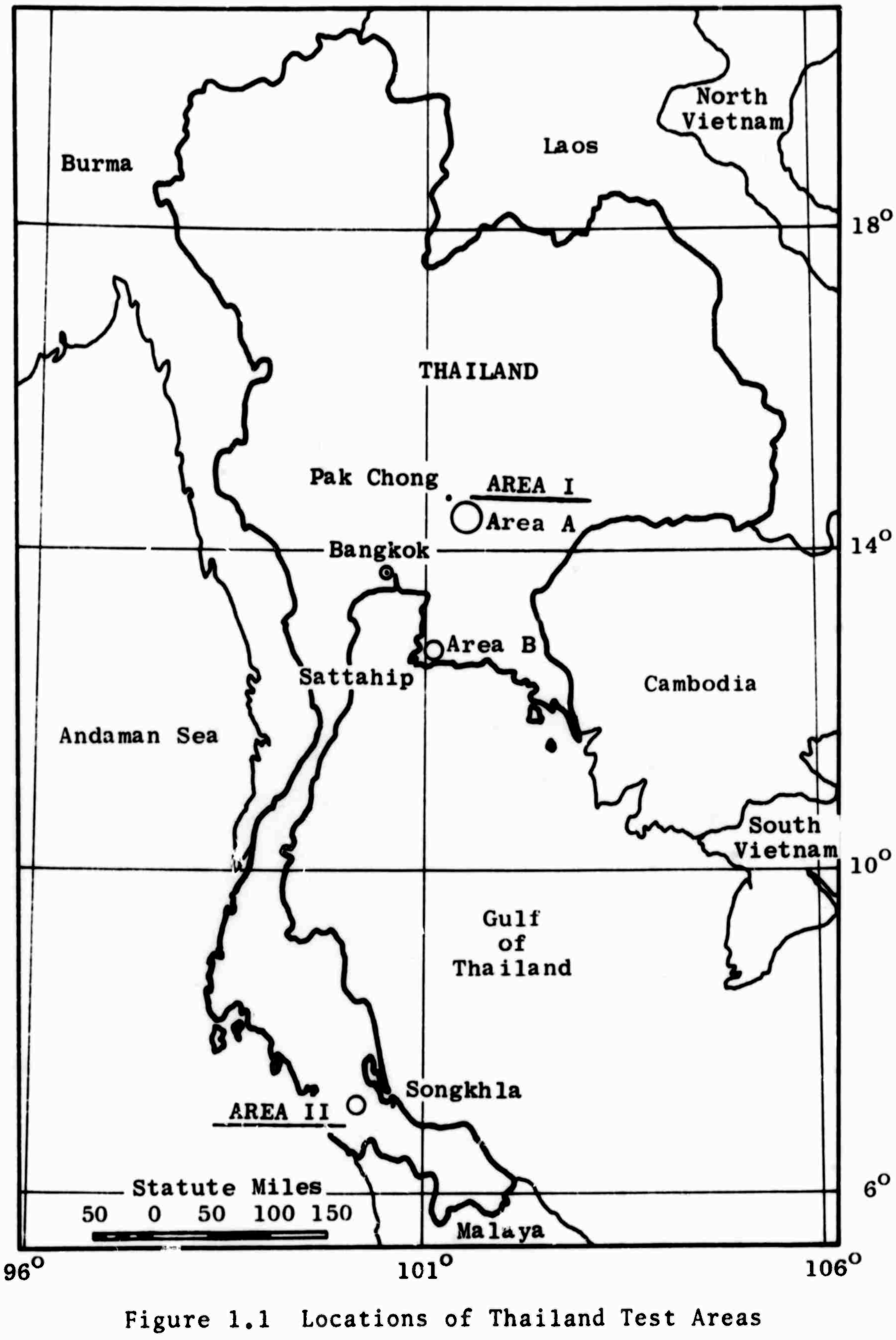

Figure 1.1 Locations of Thailand Test Areas

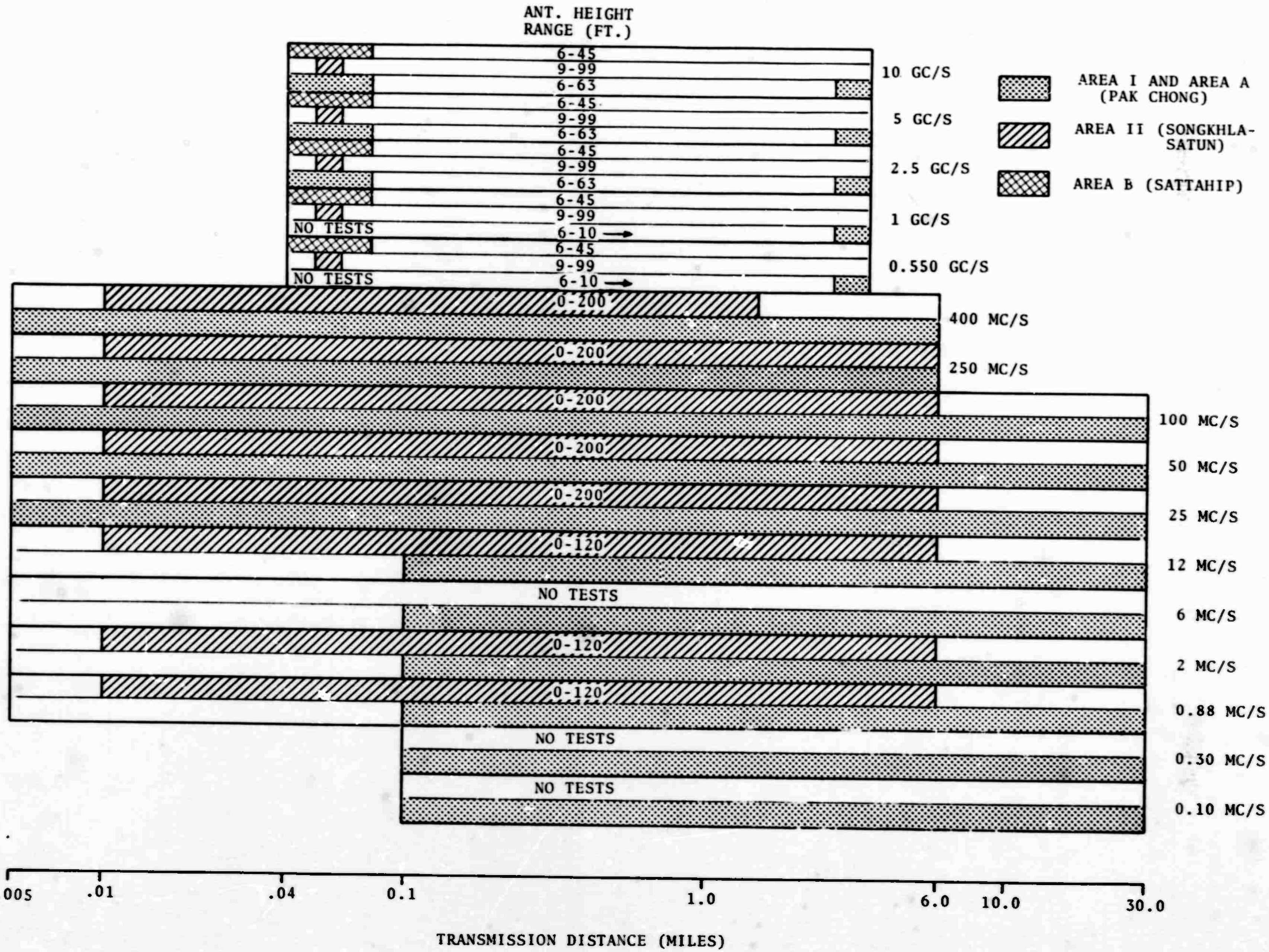

Figure 1.2 General Scope of Thailand Propagation Measurements

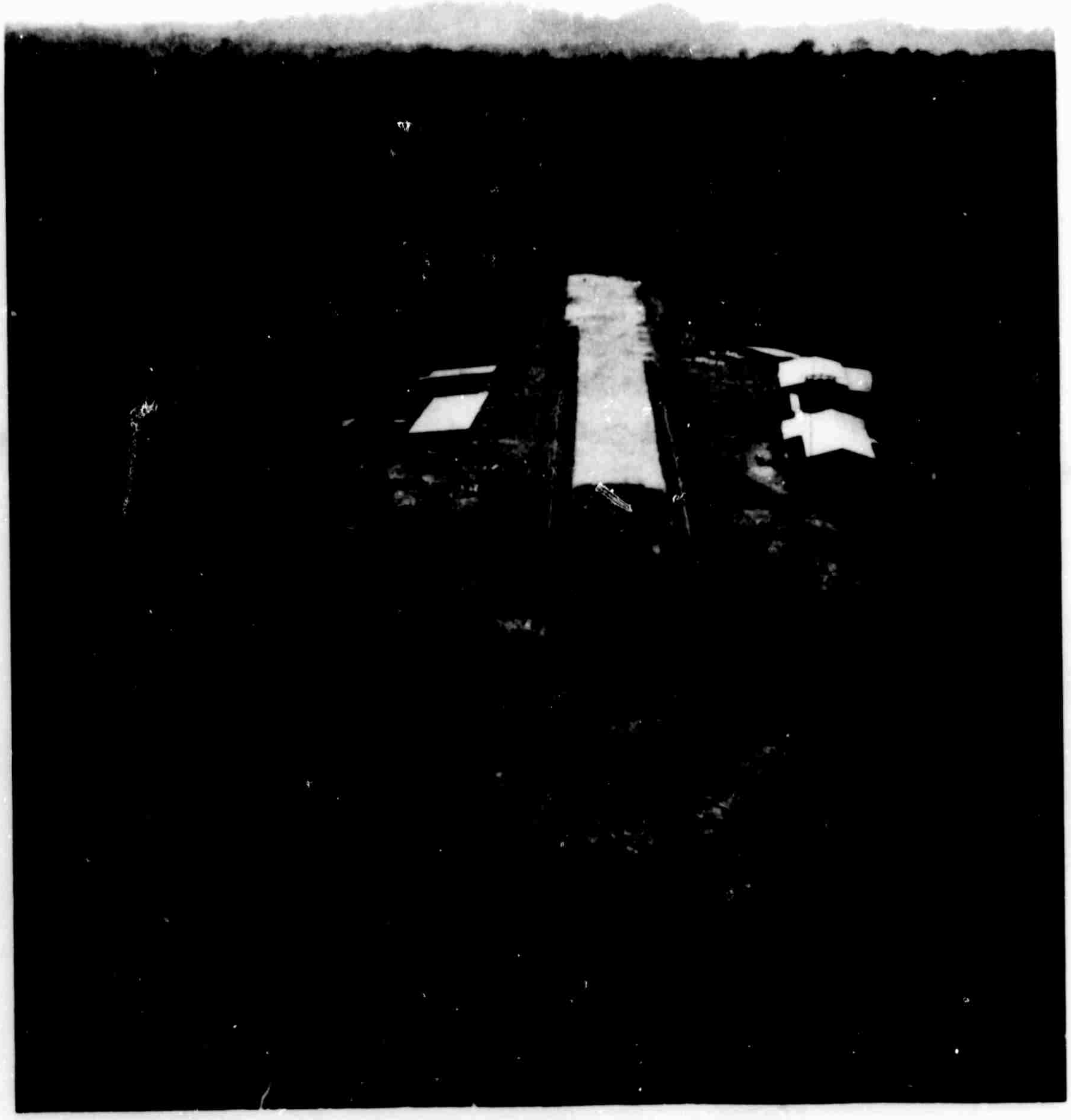

Figure 1.3 Base Camp and Landing Strip for Area II

to build a small airstrip for the STOL type aircraft which were available for ferrying personnel. The strip, shown in Figure 1.3, is rock covered and extends about 750 feet. It was completed in August 1967 and is now in constant use.

The contents of this report cover four series of propagation tests and certain environmental measurements conducted in 1967.

The following section, Section 2, presents the height-gain tests. These consist of tests at frequencies between 0.88 to 250 Mc/s. The transmitting antennas were 0, 13, 40, 80, and 120 feet above ground, and the receiving antennas sampled field strength over 20 height segments from 8 to 118-foot elevations. In general, both polarizations were tested, and transmission distances ranged from 0.05 to 5.95 miles.

Section 3 contains the results of the supplementary tests. These were a part of the walking tests presented in a previous semiannual report and involved propagation measurements with hand-held receiving antennas that were positioned at a variety of heights and orientations near ground level. Test frequencies ranged from 25 to 250 Mc/s.

Measurements of foliage-induced wave attenuation from 0.550 to 10 Gc/s are covered in Section 4. These tests were made over 300-foot transmission paths, and the results show attenuation above free-space values, both in terms of total amounts and effective attenuation per meter of foliage.

Section 5 shows transmission losses and received field variation when transmitting at 25-400 Mc/s from antennas significantly above the jungle level. This section carries the first results of the data analysis.

Section 6 summarizes the climatological measurements made at the Area II site during 1967.

Essentially all measurements in this program are presented in terms of basic path loss. The meaning and mathematics of this unit are briefly described in Section 2.2 in this report, and a more complete treatment is contained in the Final Report Volume I.[2]

Certain notations are observed throughout this report to allow a concise and standard means of describing the test parameters. Where basic transmission loss is shown in any figure or table, the following notation (described in Section 2.2) accompanies it.

$$L_b = F_L(f, H_t, P, d, H_r)$$

Where a set of values is presented that is not in terms of path loss, usually the "F_L (f, H_t, P, d, H_r)" notation is not used.

To avoid confusion when referring to data from different test sites, the locations will be called Areas I or II, with further description where necessary to indicate the particular part of the area.

2. HEIGHT-GAIN TESTS

This section describes the height-gain data and the techniques employed in the collection of that data at the Area II test site in southern Thailand. The measurements were performed on radials W, X, Y, and Z of the walking trail system, and at four distant field points identified as A, B, C, and D. Test frequencies ranged from 0.880 Mc/s to 250 Mc/s. The basic data is tabulated and presented in such a way as to group together all measurements made at a particular frequency, polarization, and transmit antenna height. This basic data is then combined by normalizing it to 1.0 mile and averaging all measurements made at each receive antenna height for a particular test configuration. The combined data is shown graphically as average basic transmission loss versus receive antenna height at an antenna separation distance of 1.0 mile. Previously reported walking data is compared with height gain data from low receive heights to indicate the accuracy and repeatability of the data.

2.1 Measurement Techniques

In the measurement tests performed at the Area II site, there were 33 combinations of frequency, polarization and antenna height in the transmitting system. By employing the method of tree diagramming from statistics, these 33 combinations are illustrated in Figure 2.1. By tracing along the branches of the diagram, each of the transmit antenna configurations is encountered. In the figure, frequency is in megacycles per second; polarization is indicated by "V" and "H" for vertical and horizontal, respectively; and antenna height is in feet as measured from the ground to the antenna feed point. The transmit antennas were dipoles and monopoles. Their construction is similar to those used in the Area I measurements. Because of the test changes made between the two areas (elimination of 0.100, 0.300, and 6.0 Mc/s test frequencies), minor modifications were made on some of the antennas. The most noticeable of these changes occurs on the 0.880 Mc/s antenna. The radiating structure remained 80 feet long with a 3-inch mean diameter; however, the top-loading structure was removed. Other antennas which received minor modifications were the 2- and 12-Mc/s horizontal dipoles.

The receive antennas used in the Area II measurements were half-wave dipoles for frequencies above 25 Mc/s and a loop for frequencies of 25 Mc/s and below.

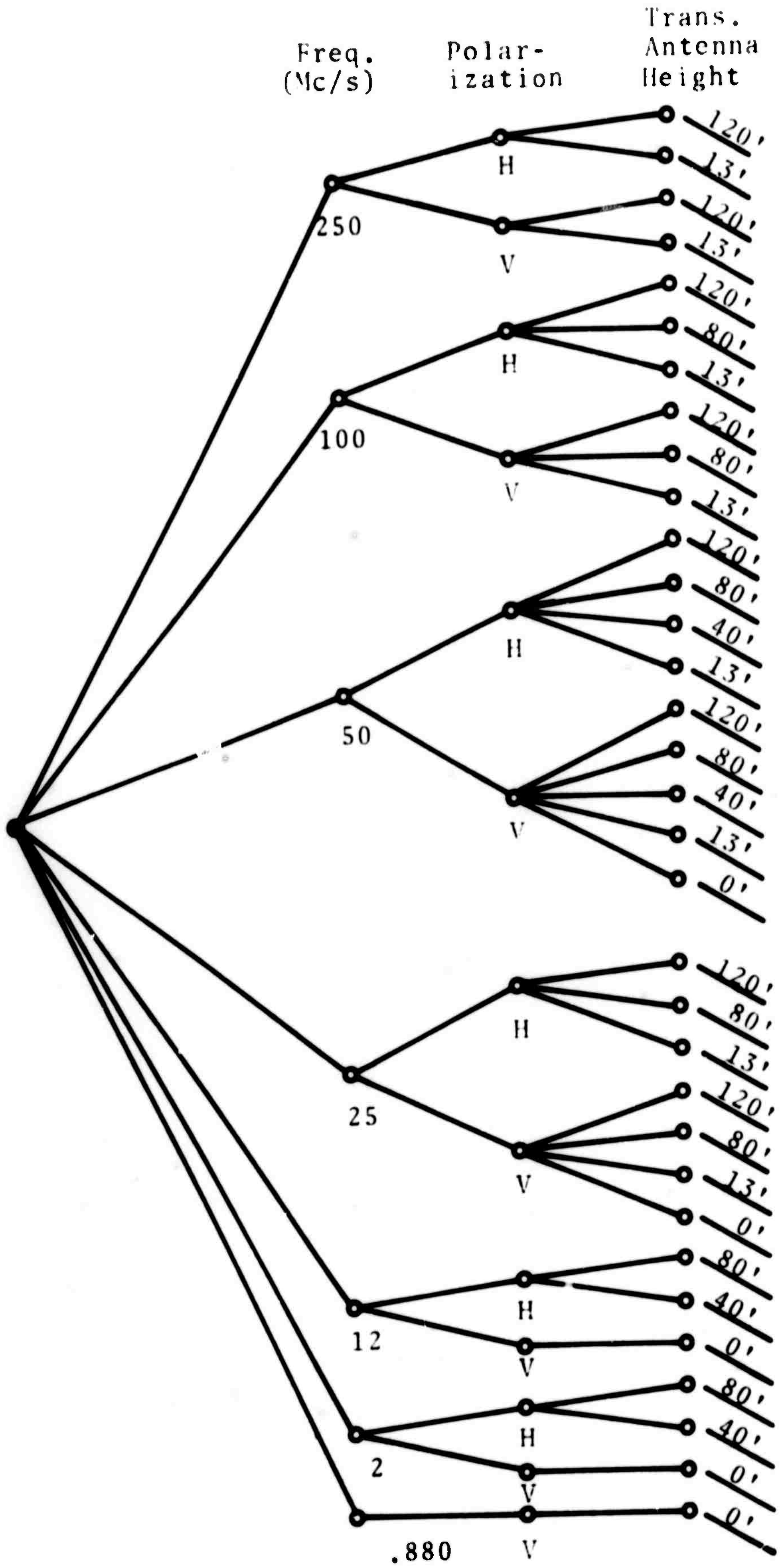

Figure 2.1 Transmitting Configurations for Height-Gain Measurements

Three transmit antenna locations were used for the measurements. These are called the VHF pad, the HF ground plane, and the clearing. Figure 2.2 shows the position of these locations with respect to the trails used for the measurements. The 2-Mc/s horizontal dipole is the only antenna erected in the clearing. Since its azimuth heading is fixed, the azimuth pattern variation is accounted for by the antenna factor employed in data reduction. All the antenna configurations with a zero transmit height (i.e., feed point at ground level as noted in Figure 2.1) were erected at the HF ground plane. All other antenna configurations, with the exception of 25, 50, 100, and 250 Mc/s at 13-foot transmit height, were erected and operated at the VHF pad. The antennas used at 13 feet were erected 50 feet from the starting point on the radial on which the measurements were being conducted. This antenna location was necessitated by the construction technique used for mounting the transmit antennas at the higher heights at the VHF pad. For tests in which horizontal polarization was employed, the axis of the transmit antenna was positioned normal to the azimuth direction of the radial or the field point at which the measurements were being made.

As mentioned before, height-gain measurements were conducted at predetermined locations on the walking trail system, and at distant field points A, B, C, and D. The positions along the radials were chosen so as to provide a maximum amount of information concerning the effects of terrain and distance with a minimum of measurement effort. The four distant field points were chosen to provide verification of the data trends established at Area I. The radial distance from each measurement point to the bench mark at the center of the trail system is listed in Table 2.1. Also shown in Table 2.1 is the azimuth heading of each radial and fixed field point.

At each measurement point the receive antenna was erected 118 feet above the ground. From this height, measurements were made in a continuous fashion as the antenna was lowered to 8 feet above the ground. Over every 5-foot increment a maximum and a minimum signal level was recorded. Then, the median of the maximum and minimum of each 5-foot section was assigned to a nominal receiver height for the measured height range. Table 2.2 shows the receiving antenna height segments which were used and the nominal receiver height assigned to each segment. The measurements made at 15 and 8 feet were fixed measurements and hence do not have an associated height range.

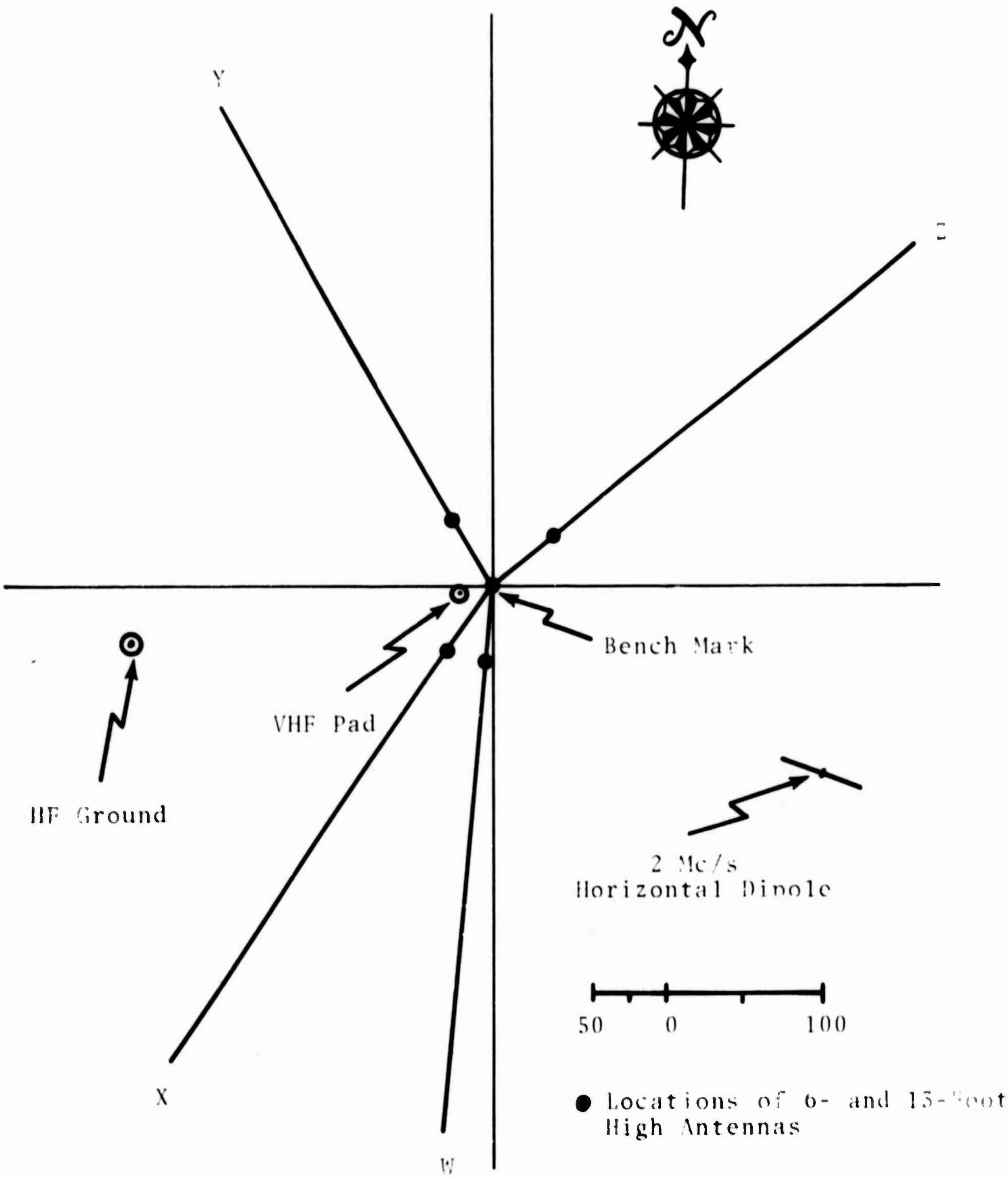

Figure 2.2 Transmitting Antenna Locations

2.2 Basic Height-Gain Data

When the data, recorded in accordance with the above techniques, was received, it was keypunched onto computer cards. The computer corrected the data to actual field strength by adding the various antenna factors and cable losses. Then, the computer compared each corrected value of field strength with the noise level present at the time of the measurements. If the signal was greater than 6 dB above the noise, no noise correction was made; if the signal was between 3 dB and 6 dB above the noise, a noise correction was applied to the data; and, if the signal was within 3 dB of the noise, that value of field strength was set equal to zero, and in subsequent calculations the value of transmission loss to be associated with it was set equal to zero.

The computer used the following equation to compute basic transmission loss.

$$L_b\,(\mathrm{dB}) = 36.57 + 20 \log F_{Mc/s} + E_o\,(\mathrm{dB}) - E_{meas}\,(\mathrm{dB})$$

where

L_b = basic transmission loss

$F_{Mc/s}$ = frequency in megacycles per second

E_o = free space field strength at 1 mile

E_{meas} = measured field strength

For a complete discussion of it, the reader is referred to a previous project report.[2] The maximum and the minimum field strengths at each receiver height interval were converted by this equation to minimum and maximum basic transmission losses for the same height interval. The average value of the minimum and maximum transmission loss, if neither equaled zero, is assigned to the nominal receiver height associated with the particular receiver height interval being considered. Lastly, the average basic transmission losses for all measurements made with a particular transmit antenna configuration were tabulated. These sets of values are presented in Tables 2.3 through 2.35.

The experimental variables appearing on each table are identified in the same systematic method as was used in previous reports; namely,

Table 2.1

DISTANCE AND HEADING FROM BENCH MARK TO 17 MEASUREMENT LOCATIONS

Radial	Fixed Field Point	Distances (miles)	Azimuth Heading (degrees)
W		0.45 & 1.0	190
X		0.2, 0.45 & 1.0	215
Y		0.1, 0.45, 1.0 & 1.5	325
Z		0.05, 0.2, 0.7 & 1.5	40
	A	2.6	331
	B	4.8	328
	C	5.95	270
	D	2.95	166

Table 2.2

HEIGHT RANGES USED IN HEIGHT-GAIN STUDY

Nominal Height (feet)	Corresponding Height Range (feet)
8	8
15	15
23	20 - 26
28	26 - 31
34	31 - 37
40	37 - 42
45	42 - 47
50	47 - 53
55	53 - 58
60	58 - 63
65	63 - 68
70	68 - 73
75	73 - 78
80	78 - 83
85	83 - 88
90	88 - 93
95	93 - 98
100	98 - 103
105	103 - 108
110	108 - 113
115	113 - 118

$$L_b = F(f, H_t, P, d, H_r)$$

This format relates the basic transmission loss derived from measurement to five basic variables: frequency in megacycles per second, f; transmitting antenna height in feet, h_t; horizontal or vertical polarization, P; distance in miles, d; and receiving antenna height in feet, H_r. The identification given on the first table (Table 2.3) is

$$L_b = F_L\ (0.880, 0, V, d, H_r)$$

This identification indicates that the receiving antenna height and distance were varied while the other three variables remained fixed at the values indicated. The subscript "L" is a general subscript indicating that measurements were made at numerous field locations. These locations are, for example, 0.45 mile on radial W, 1.0 mile on radial X, fixed field point A, etc. This notation will be used throughout this report.

In addition to this nomenclature, a symbol is associated with each value of average basic transmission loss inserted into the tables. These symbols listed below are supplied to distinguish those measurements which were noise affected from those which were not.

" " No symbol means no noise corrections were applied to the data.

"#" Indicates a noise correction on either the maximum or minimum basic transmission loss calculation.

"*" Indicates a noise correction made on both maximum and minimum basic transmission loss calculations.

"$" Indicates either the maximum or the minimum basic transmission loss calculation corrected to zero, which also sets basic transmission loss equal to zero.

Table 2.3

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(.880, 0, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.20	X	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
0.45	X	39	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
1.00	X	50	50	50	50	50	50	50	50	50	50	50	50	50	51	51	51	51	51	51	51	51
0.10	Y	22	22	22	22	22	22	22	22	22	22	22	23	23	24	24	24	24	24	24	24	24
0.45	Y	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	41	41
1.00	Y	52	53	53	53	53	53	53	53	53	53	53	53	53	53	54	54	54	54	54	54	54
1.50	Y	60	60	60	60	61	61	61	61	61	61	61	62	62	62	62	62	62	62	62	62	62
0.05	Z	20	20	20	20	20	20	20	21	21	21	21	21	21	21	21	21	21	21	21	21	21
1.50	Z	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60

Table 2.4

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b \doteq F_L(2, 0, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	58	58	58	58	58	58	58	58	58	59	59	59	59	59	59	59	59	59	59	59	59
1.00	W	73	73	73	73	73	74	74	74	74	74	75	75	75	75	75	76	76	76	76	76	76
0.20	X	41	41	41	42	42	42	42	42	42	42	42	42	42	42	42	43	43	43	43	43	43
0.45	X	57	58	59	59	59	59	59	59	60	60	60	60	60	60	61	61	61	62	62	62	62
1.00	X	75	75	76	76	76	76	77	77	77	78	78	78	79	79	79	80	80	80	80	80	80
0.10	Y	34	34	34	34	35	35	35	35	36	36	36	36	36	37	37	37	37	37	37	37	37
0.45	Y	59	59	60	60	60	60	61	61	61	61	62	62	62	62	63	63	63	63	63	63	63
1.00	Y	77	78	78	79	79	79	79	79	80	80	81	81	81	81	81	81	82	82	82	82	82
1.50	Y	86	86	86	86	87	87	87	87	88	88	88	88	88	89	89	89	89	89	89	89	89
0.05	Z	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
0.20	Z	45	45	45	46	46	46	46	47	47	47	47	47	47	47	48	48	48	49	49	49	49
0.70	Z	70	70	70	71	71	71	71	71	72	72	72	72	71	71	70	70	69	69	68	68	67
1.50	Z	84	84	84	84	84	84	84	85	85	85	86	86	86	86	86	86	86	86	86	86	86
2.60	A	97	96	96	96	96	96	96	97	96	96	97	97	96	95	95	94	93	92	92	91	91
4.80	B	105	104	104	104	105	105	105	105	106	106	106	106	106	106	106	107	107	107	107	108	108
5.95	C	104	104	104	104	105	105	105	105	105	105	105	104	104	103	102	102	102	101	101	100	100
2.95	D	89	89	89	90	90	90	90	90	90	90	90	90	90	90	91	91	91	91	91	91	91

Table 2.5

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(2, 40, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	M	74	73	69	67	65	64	63	62	61	61	61	60	59	58	58	57	57	56	56	56	56
1.00	M	90	86	84	83	82	81	80	80	79	78	78	77	77	76	76	75	75	75	74	74	74
0.20	X	63	66	62	59	56	55	54	53	53	53	52	52	51	51	50	50	49	49	49	49	48
0.45	X	77	76	74	72	71	70	69	68	67	66	66	66	65	64	63	62	61	60	60	60	60
1.00	X	88	86	84	83	82	81	81	80	80	80	79	79	78	78	77	77	76	76	75	75	74
0.10	Y	58	63	61	58	56	55	55	54	52	50	50	50	49	48	48	47	47	46	46	46	45
0.45	Y	81	75	75	74	73	72	71	71	71	71	71	70	69	69	67	66	66	66	66	65	64
1.00	Y	89	86	85	83	82	81	81	80	80	80	80	79	79	78	78	77	77	76	76	76	76
1.50	Y	101	99	97	95	93	92	91	90	89	88	88	87	86	86	85	85	85	85	84	83	83
0.05	Z	40	42	39	37	36	35	34	33	32	31	31	30	30	29	29	28	28	28	28	27	27
0.20	Z	60	57	54	52	51	50	49	48	47	46	45	44	44	44	43	43	42	42	42	41	40
0.70	Z	80	78	76	70	64	63	62	60	59	59	58	58	58	57	57	56	56	56	61	65	64
1.50	Z	87	85	83	82	82	81	80	79	78	77	76	75	75	74	74	73	73	73	72	72	72
2.60	A	101	98	96	93	92	91	91	90	89	89	88	88	87	87	86	86	85	85	85	84	84
4.80	B	113	109	108	107	106	104	103	102	101	100	99	99	98	98	97	96	96	95	95	94	94
5.95	C	* 0	*110	*110	*109	*110	*112	*111	*110	*110	*110	*109	*109	*109	#108	106	105	104	104	104	104	104
2.95	D	101	* 0	101	100	99	98	97	95	94	93	92	92	91	90	90	89	88	88	87	86	86

Table 2.6

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(2,\ 80,\ H,\ d,\ H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	70	68	65	64	62	61	60	59	58	57	57	57	56	56	55	55	55	55	54	54	54
1.00	W	86	84	81	80	79	78	77	76	76	75	75	74	74	73	73	72	72	71	71	71	71
0.20	X	63	62	60	58	57	56	55	54	52	51	50	50	49	49	48	47	47	46	46	46	45
0.45	X	75	77	74	72	70	69	68	66	65	64	63	62	61	60	60	6[illegible]	59	58	58	58	58
1.00	X	85	83	81	80	79	78	77	76	76	75	74	74	73	73	73	72	72	71	71	71	70
0.10	Y	61	60	58	56	55	54	52	50	50	49	48	48	47	47	40	45	44	44	43	43	42
0.45	Y	82	77	74	75	73	72	71	70	69	68	67	67	67	66	66	65	65	64	64	63	62
1.00	Y	87	85	83	82	81	80	79	78	77	77	76	76	76	75	75	75	75	74	74	74	74
1.50	Y	98	96	93	91	90	89	88	87	87	86	85	84	84	84	83	82	82	82	81	81	80
0.05	Z	40	41	38	36	35	34	33	32	31	30	29	28	28	27	27	26	26	26	25	25	24
0.20	Z	46	44	41	39	38	36	35	34	34	33	33	3[illegible]	32	31	31	31	31	30	30	30	29
0.70	Z	77	76	73	72	71	70	69	68	67	67	66	66	65	64	64	63	63	63	62	62	62
1.50	Z	85	84	83	81	80	78	77	76	76	76	75	75	75	75	74	74	74	74	73	73	72
2.60	A	98	98	95	92	91	90	89	88	87	86	86	85	85	84	84	83	83	83	82	82	81
4.80	B	112	109	106	104	102	100	99	98	98	97	97	96	95	95	94	94	93	93	92	92	91
5.95	C	* 0	* 0	* 0	* 0	* 0	* 0	*112	*111	*109	*109	*109	*108	106	106	105	104	103	103	102	102	101
2.95	D	* 0	102	97	96	95	94	93	92	91	90	89	88	88	87	87	86	86	85	85	84	84

Table 2.7

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(12, 0, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	116	117	118	117	116	115	114	112	110	109	109	108	107	106	105	105	104	102	101	101	101
1.00	W	122	122	119	118	115	113	112	111	110	109	108	107	106	105	104	104	103	102	102	101	100
0.20	X	95	96	96	95	94	93	91	89	87	85	84	83	81	80	80	79	79	78	78	77	76
0.45	X	108	107	106	106	104	102	101	100	98	97	96	95	95	94	93	92	91	91	91	91	90
1.00	X	119	121	123	122	121	119	118	117	116	115	115	114	112	111	110	110	109	109	108	108	107
0.10	Y	92	85	87	87	86	84	81	79	78	77	75	74	73	72	70	69	68	67	67	66	66
0.45	Y	98	105	103	102	100	99	97	96	94	93	92	91	90	90	89	86	87	87	86	85	85
1.00	Y	109	113	113	112	111	109	108	105	104	104	102	100	99	98	97	96	96	95	94	94	93
1.50	Y	126	121	119	117	116	115	115	114	113	111	109	108	107	106	105	105	104	103	103	102	102
0.05	Z	72	74	74	73	72	70	69	68	67	66	65	64	63	62	61	60	60	58	57	56	56
0.20	Z	86	85	86	85	85	84	82	80	79	78	78	76	75	75	75	74	74	73	73	72	72
0.70	Z	105	104	108	110	112	110	106	104	104	102	99	97	97	98	97	96	97	98	98	98	97
1.50	Z	117	119	122	124	123	120	118	116	117	118	116	114	113	113	112	112	114	114	112	111	109
2.60	A	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	#123	120	119	117	116	115	114	112	111	112	112	112	112
4.80	B	*136	*137	*137	*136	#135	133	131	130	129	128	127	126	125	124	124	123	123	122	122	122	121
5.95	C	138	138	139	140	140	140	138	135	134	134	134	133	131	131	130	128	127	127	127	127	126
2.95	D	130	131	132	131	130	128	126	125	125	124	123	121	120	119	118	117	117	116	116	115	114

Table 2.8

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(12,\ 40,\ H,\ d,\ H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	86	81	78	77	75	74	73	72	72	71	71	70	70	69	69	69	69	68	68	58	67
1.00	W	100	94	92	90	89	88	88	87	86	85	85	84	84	83	83	82	82	82	81	80	80
0.20	X	74	68	65	63	62	61	60	59	58	57	57	56	55	54	54	54	54	53	53	53	52
0.45	X	81	77	75	73	72	71	70	69	68	68	67	67	67	67	66	66	66	66	66	65	65
1.00	X	97	91	88	87	86	84	83	82	82	81	80	80	79	79	79	79	78	78	77	77	77
0.10	Y	71	66	61	58	56	54	52	51	49	48	47	47	46	45	45	44	43	43	42	42	41
0.45	Y	86	82	78	76	75	74	73	72	71	70	70	69	68	68	68	67	67	66	66	65	65
1.00	Y	95	91	86	84	82	81	80	79	79	78	78	78	77	77	77	76	76	76	76	76	75
1.50	Y	106	99	94	92	91	89	87	86	86	86	85	84	84	84	83	83	83	83	83	83	82
0.05	Z	50	45	43	41	39	38	37	35	34	34	33	33	32	31	31	30	30	30	29	29	29
0.20	Z	70	64	60	58	57	56	55	54	54	53	52	52	52	51	51	51	51	50	50	50	50
0.70	Z	93	85	83	82	81	80	79	79	78	78	78	78	78	78	78	78	77	77	77	76	76
1.50	Z	93	91	86	84	84	83	82	82	82	82	82	81	81	81	81	81	80	80	80	80	80
2.60	A	114	112	106	103	102	100	99	98	97	96	95	94	94	94	94	93	93	93	92	92	92
4.80	B	123	121	117	115	113	112	111	110	109	109	108	108	107	106	106	105	105	104	103	103	103
5.95	C	126	122	118	117	115	114	113	112	112	111	110	109	109	108	108	108	108	108	107	107	106
2.95	D	118	113	109	108	106	105	104	103	102	102	101	101	100	100	99	99	98	98	97	97	97

Table 2.9

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(12, 80, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	80	75	71	69	68	66	65	64	63	63	63	62	62	61	61	61	61	60	60	60	59
1.00	W	92	88	84	83	81	80	79	78	77	77	76	76	76	75	75	74	74	73	72	72	72
0.20	X	71	65	62	60	59	57	56	56	55	54	52	52	51	51	51	51	50	50	50	50	49
0.45	X	83	74	72	69	68	67	66	66	66	65	65	65	65	65	64	65	65	64	64	63	63
1.00	X	90	86	83	81	80	78	77	77	76	76	75	74	74	74	73	73	73	73	72	72	72
0.10	Y	61	55	52	50	48	47	46	45	44	43	42	41	41	40	40	39	39	39	39	40	39
0.45	Y	81	77	74	72	71	70	69	68	68	67	66	66	66	65	64	63	63	62	62	62	61
1.00	Y	90	84	81	79	78	77	76	75	75	74	74	73	73	73	72	72	72	72	71	71	71
1.50	Y	102	95	91	89	87	86	84	84	83	82	81	81	80	80	80	80	79	79	79	79	79
0.05	Z	45	39	38	36	34	33	32	31	30	30	29	29	29	28	28	28	28	29	29	30	31
0.20	Z	64	58	55	53	52	51	50	50	49	48	48	47	47	46	46	46	45	45	45	45	44
0.70	Z	90	81	79	78	77	76	75	75	74	74	74	74	73	73	73	73	73	73	73	72	72
1.50	Z	93	90	84	82	82	81	80	79	79	78	78	77	77	77	76	76	76	76	76	75	75
2.60	A	108	106	101	98	97	95	94	93	92	91	91	90	89	89	88	88	88	88	88	87	87
4.80	B	120	118	113	111	109	108	107	106	106	105	105	104	103	102	102	101	100	100	100	99	99
5.95	C	121	116	112	110	109	108	107	106	106	105	104	104	104	103	103	102	102	101	101	101	100
2.95	D	112	107	103	101	100	99	98	97	96	96	96	95	95	94	93	93	92	92	91	91	91

Table 2.10

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(25, 0, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	60	85	90	95	100	105	110	115
0.45	W	120	115	115	115	114	111	109	108	107	106	105	104	103	105	106	105	105	105	105	103	101
1.00	W	125	119	116	114	112	111	109	108	107	106	106	105	104	103	102	102	101	100	100	99	99
0.20	X	104	110	108	106	106	106	104	96	90	81	86	89	88	87	85	84	83	83	82	81	81
0.45	X	120	118	110	108	107	106	106	105	105	105	104	104	103	102	101	99	98	97	96	95	95
1.00	X	* 0	129	125	122	121	121	120	119	118	118	117	117	117	118	118	116	116	115	115	115	113
0.10	Y	85	83	82	79	77	76	76	76	75	75	75	74	74	73	72	71	71	70	70	70	70
0.45	Y	114	116	114	112	111	110	110	110	109	109	109	108	107	106	105	103	101	101	100	99	98
1.00	Y	129	125	122	120	119	116	113	112	112	111	110	109	109	109	109	108	108	106	105	104	102
1.50	Y	* 0	* 0	* 0	* 0	$ 0	#128	125	125	125	125	123	121	120	118	116	115	115	114	113	112	112
0.05	Z	94	92	91	89	88	87	88	92	93	95	89	85	82	79	77	76	76	75	74	73	73
0.20	Z	113	102	101	99	97	95	94	93	92	92	91	90	89	88	88	87	88	87	86	86	85
0.70	Z	*129	*129	*129	*129	*129	#127	124	122	123	125	124	123	121	116	113	112	112	111	111	110	110
1.50	Z	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	*127	*127	*127	*126	*125	*125	*125	*126	#124	122	121	120	119
2.60	A	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	*125	*125	*124	*124	*124	#122	120	120
4.80	B	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0
5.90	C	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0
2.95	D	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0

Table 2.11

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(25, 13, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	122	122	120	116	112	111	110	108	107	106	106	105	103	102	102	102	101	101	101	100	99
1.60	W	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	$0	113	113	112	112	111	110
0.20	X	108	110	109	106	104	101	101	100	101	101	99	99	100	99	98	95	94	91	91	90	92
0.45	X	123	116	113	110	108	107	106	105	104	104	103	102	101	100	99	98	97	97	96	95	94
1.00	X	*136	131	130	128	126	124	123	122	122	120	119	119	118	118	117	117	116	115	114	113	113
0.10	Y	92	86	84	83	83	82	81	79	77	75	74	74	73	72	72	72	71	71	71	70	70
0.45	Y	118	116	115	114	113	113	112	111	110	110	109	109	108	108	107	106	104	103	102	104	102
1.00	Y	141	140	136	132	129	127	125	123	123	123	122	122	122	120	119	119	118	117	115	114	113
1.50	Y	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	$0	*126	*124	*124	#122	121
0.05	Z	60	62	61	59	57	55	54	54	54	54	54	54	54	53	51	51	51	51	50	50	49
0.20	Z	95	91	89	87	86	85	85	85	84	82	81	81	79	78	77	76	76	75	74	74	73
0.70	Z	124	125	125	125	121	117	116	116	117	117	119	118	115	112	110	109	108	107	107	106	106
1.50	Z	*0	*0	*0	*0	*0	$0	*129	*127	#124	122	122	122	122	121	120	118	117	116	116	116	115
2.60	A	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	$0	*126	*126	*126	*126	*125
4.80	B	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0
5.95	C	*0	165	158	158	158	158	158	158	157	154	152	151	150	149	148	146	145	144	144	142	140
2.95	D	*0	*0	*0	*0	*0	$0	*129	*128	*127	*126	*126	*126	#124	123	122	120	119	119	118	118	117

Table 2.12

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(25, 80, V, d, H_r)$

DIST (MI)	LOC	8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
		RECEIVE HEIGHT (FEET)																				
0.45	W	101	99	96	94	92	90	90	89	87	86	85	84	83	82	81	80	79	78	77	76	76
1.00	W	122	119	112	109	107	105	103	102	101	100	98	97	96	96	95	95	93	92	92	91	91
0.20	X	87	87	85	83	81	80	79	78	77	75	74	72	71	70	69	68	68	67	66	66	65
0.45	X	106	101	98	95	93	92	91	90	88	86	85	83	83	82	81	80	80	80	79	77	76
1.00	X	118	109	107	104	102	101	99	99	98	96	95	94	93	92	92	91	90	90	89	89	89
0.10	Y	88	83	81	83	82	76	72	70	67	63	60	59	59	59	58	58	58	57	57	57	56
0.45	Y	102	94	93	92	91	90	89	88	88	87	86	85	85	84	82	81	81	80	79	78	78
1.00	Y	115	112	110	108	105	102	99	97	97	96	96	95	94	93	92	92	91	90	89	88	88
1.50	Y	115	116	115	114	112	110	110	109	108	107	105	104	103	101	100	99	99	98	97	97	96
0.05	Z	53	59	59	58	57	56	54	54	54	52	50	49	47	46	45	44	44	44	43	43	42
0.20	Z	86	79	77	76	75	73	74	76	73	70	69	68	67	66	65	64	63	63	63	62	62
0.70	Z	110	109	107	106	104	103	102	101	101	100	99	97	95	93	92	90	89	89	89	89	88
1.50	Z	*127	116	113	112	111	110	109	108	107	105	103	103	103	102	102	101	101	99	98	97	96
2.60	A	123	123	123	122	120	118	118	118	118	117	115	113	113	113	112	111	111	110	108	107	106
4.80	B	* 0	*131	*130	#127	126	125	124	123	123	123	122	121	120	119	119	119	118	118	117	117	117
5.95	C	* 0	* 0	151	150	148	147	146	144	141	140	137	134	132	131	130	128	126	125	125	125	123
2.95	D	*128	123	121	119	117	115	115	114	113	113	112	111	110	109	108	107	106	105	104	104	103

Table 2.13

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(25, 120, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	93	92	89	85	82	80	78	77	77	76	75	74	73	73	72	71	70	69	68	67	66
1.00	W	113	104	100	98	96	94	93	92	91	90	88	87	86	86	85	85	85	84	83	82	82
0.20	X	81	82	79	76	74	73	72	70	70	68	67	66	65	64	63	63	62	61	60	60	60
0.45	X	101	95	92	89	86	84	82	81	80	79	78	77	77	76	75	74	73	72	72	71	71
1.00	X	106	104	101	98	95	94	93	92	90	89	88	88	87	86	86	85	84	83	83	82	82
0.10	Y	71	73	74	72	69	65	61	59	58	58	56	55	54	54	53	53	52	52	51	51	50
0.45	Y	95	89	87	86	85	84	83	83	82	81	80	79	79	78	77	76	75	74	74	73	73
1.00	Y	109	107	103	100	98	96	94	93	93	92	91	90	89	88	87	86	85	84	84	83	82
1.50	Y	109	112	110	108	107	105	104	102	101	101	100	98	97	95	94	93	92	92	91	91	91
0.05	Z	52	57	54	52	51	50	49	48	47	47	46	46	45	43	42	41	41	40	40	40	40
0.20	Z	78	72	70	68	66	65	65	64	64	63	61	60	59	58	57	56	56	55	55	55	55
0.70	Z	102	101	100	101	101	100	98	96	95	95	94	92	89	86	85	84	83	83	83	83	82
1.50	Z	119	110	107	106	104	102	101	100	99	98	97	96	95	95	94	94	93	92	91	90	89
2.60	A	116	117	118	118	114	111	108	108	111	111	109	109	108	106	105	105	104	103	103	102	99
4.80	B	* 0	* 0	$ 0	*127	#125	122	120	119	118	117	115	115	114	113	113	112	112	111	110	110	109
5.95	C	* 0	* 0	* 0	$ 0	#132	130	130	130	130	127	124	123	121	119	119	119	118	117	116	116	115
2.95	D	121	118	115	114	113	111	110	109	107	107	106	105	104	103	102	101	100	99	98	97	96

Table 2.14

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(25, 13, H, d, H_r)$

CIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	94	88	85	82	81	80	79	78	77	76	76	76	76	76	76	76	76	76	76	75	75
1.00	W	102	98	96	95	94	94	93	93	92	91	90	90	89	89	88	87	87	86	86	85	85
0.20	X	91	91	88	87	86	86	86	87	88	87	87	87	86	85	84	83	81	79	77	76	75
0.45	X	99	97	94	92	91	91	90	90	90	90	90	90	89	88	88	87	87	86	86	86	85
1.00	X	116	110	106	104	103	103	102	102	101	101	101	100	100	100	100	99	99	98	98	98	97
0.10	Y	63	64	62	61	60	59	58	58	57	56	55	55	54	54	54	53	53	52	52	52	52
0.45	Y	100	101	99	98	96	93	91	90	88	85	83	82	81	79	79	78	78	77	77	77	77
1.00	Y	109	105	102	100	98	97	96	95	95	95	95	95	95	95	95	95	94	93	92	92	92
1.50	Y	109	107	105	105	105	105	106	106	106	106	107	107	107	107	106	104	103	103	102	101	101
0.05	Z	54	49	47	45	43	42	41	40	39	39	38	38	38	38	37	37	37	37	37	37	36
0.20	Z	100	79	76	74	71	69	68	66	65	65	64	64	64	63	63	62	62	62	61	61	60
0.70	Z	105	99	97	96	95	96	96	96	95	94	93	93	92	92	91	91	91	90	89	88	88
1.50	Z	116	111	107	105	104	103	104	105	105	105	105	104	103	103	102	102	101	101	101	101	101
2.60	A	122	118	116	115	114	114	114	114	114	114	113	112	112	112	113	113	113	112	112	111	109
4.80	B	*142	135	132	130	129	128	127	126	126	125	124	124	124	124	123	123	123	123	123	123	122
5.95	C	144	144	142	141	140	140	139	138	137	134	132	131	131	130	129	129	128	128	127	127	126
2.95	D	* 0	126	123	121	120	119	118	118	118	117	116	116	116	115	115	115	114	114	113	113	112

Table 2.15

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(25, 80, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	87	82	77	75	74	72	71	70	70	70	69	69	69	69	69	69	68	68	67	67	66
1.00	W	95	91	89	88	87	86	8[illegible]	85	84	84	83	82	82	82	81	80	80	79	79	78	78
0.20	X	67	64	62	60	60	60	60	60	59	59	59	59	58	58	58	58	58	58	57	56	55
0.45	X	81	80	76	74	73	73	73	72	72	72	71	71	71	72	71	71	70	70	69	69	68
1.00	X	96	92	89	87	87	86	85	85	84	84	83	83	82	82	82	81	81	81	80	80	80
0.10	Y	56	56	53	52	51	50	49	48	47	46	45	45	45	45	45	46	46	47	48	48	49
0.45	Y	90	91	90	88	86	84	83	81	79	77	75	74	72	71	71	70	69	68	68	68	68
1.00	Y	101	97	94	92	90	90	89	89	88	88	87	87	87	87	86	85	85	84	84	83	83
1.50	Y	100	98	95	95	95	95	95	96	96	96	97	98	97	97	96	94	93	93	93	92	91
0.05	Z	44	39	38	37	36	35	36	37	38	39	41	43	46	47	45	42	39	38	37	36	35
0.20	Z	81	67	64	62	60	58	56	56	55	54	54	54	54	54	54	55	55	55	56	56	57
0.70	Z	98	92	90	88	88	88	89	89	88	87	86	86	86	85	85	85	84	83	82	82	81
1.50	Z	109	103	100	98	96	96	96	97	98	97	97	96	96	95	95	95	95	95	94	94	93
2.60	A	114	110	106	104	104	104	104	104	103	102	102	102	102	102	102	103	103	102	101	100	99
4.80	B	*128	122	118	117	116	115	114	114	113	113	112	112	112	111	111	111	110	110	110	110	109
5.95	C	132	131	129	128	127	126	124	123	122	121	120	119	117	116	115	114	114	113	113	112	112
2.95	D	118	123	123	122	120	119	116	114	110	104	101	99	99	99	98	98	97	97	96	96	95

Table 2.16

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(25,\ 120,\ H,\ d,\ H_r)$

DIST (MI)	LCC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	85	79	74	72	70	69	67	67	67	66	66	66	66	66	66	66	66	65	65	64	63
1.00	W	92	88	85	85	84	83	82	81	81	80	79	79	78	78	77	76	76	75	75	75	75
0.20	X	66	63	61	59	57	57	57	57	57	57	57	57	57	57	57	57	57	58	58	58	57
0.45	X	79	77	75	73	72	71	71	71	71	71	71	71	71	70	70	71	71	71	71	70	69
1.00	X	94	90	87	85	84	84	83	83	82	82	81	81	81	80	80	80	80	80	80	79	78
0.10	Y	54	53	49	47	46	45	44	44	44	45	46	47	49	51	54	56	55	52	49	48	46
0.45	Y	88	88	85	83	81	80	79	77	75	74	73	72	71	70	69	69	68	68	67	67	67
1.00	Y	98	94	91	89	87	86	85	85	85	84	84	84	84	84	83	83	82	82	81	81	80
1.50	Y	96	94	92	92	92	92	92	92	92	93	93	94	94	93	92	91	90	90	89	89	88
0.05	Z	42	40	38	37	37	38	41	46	50	47	41	39	37	36	36	37	38	41	42	41	39
0.20	Z	72	64	59	57	55	54	53	53	53	53	53	53	54	55	56	57	58	59	58	58	57
0.70	Z	94	87	85	85	85	85	86	85	84	83	82	81	81	81	81	80	79	79	78	73	77
1.50	Z	104	98	95	93	92	92	92	92	93	93	92	91	91	90	90	89	89	89	89	89	88
2.60	A	112	109	105	103	102	102	102	102	102	101	100	100	100	100	100	101	101	101	100	99	98
4.80	B	124	120	116	114	113	112	111	111	110	109	109	109	108	108	108	107	107	107	106	106	106
5.95	C	130	129	127	126	124	123	122	121	120	119	118	117	115	114	113	113	112	112	111	110	109
2.95	D	115	107	103	101	100	98	97	96	96	96	95	95	95	94	94	93	92	92	92	92	91

Table 2.17

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(50,\ 0,\ V,\ d,\ H_r)$

DIST (MI)	LOC	8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
		RECEIVE HEIGHT (FEET)																				
0.45	W	121	118	121	120	119	116	115	110	110	108	108	107	104	102	100	99	98	97	96	96	96
1.00	W	*144	142	#141	#140	135	132	130	126	123	121	120	119	118	117	115	114	113	113	112	112	111
0.20	X	110	106	104	103	101	100	98	99	98	98	98	98	97	97	95	92	90	89	88	87	87
0.45	X	119	116	135	129	132	129	131	133	130	129	125	119	115	114	113	111	110	109	109	108	109
1.00	X	137	130	130	128	125	123	122	120	119	120	120	119	118	115	113	112	111	110	109	109	108
0.10	Y	103	89	86	83	80	80	80	78	79	80	81	86	92	91	90	90	87	83	79	76	77
0.45	Y	122	125	123	118	114	112	111	112	113	115	115	113	110	107	104	103	102	101	100	98	97
1.00	Y	149	143	138	135	134	137	137	134	131	130	129	127	127	128	128	126	127	127	126	124	125
1.50	Y	149	147	145	145	143	146	146	142	137	134	132	134	136	137	136	135	135	135	134	135	128
0.05	Z	90	88	97	99	102	102	96	92	101	101	97	90	84	80	77	74	72	70	68	67	67
0.20	Z	121	111	111	114	112	108	107	105	106	109	110	111	114	115	109	104	106	107	105	103	101
0.70	Z	135	129	127	127	126	126	124	123	122	122	122	124	123	125	128	129	128	126	124	121	118
1.50	Z	143	141	129	128	127	127	129	131	131	127	123	123	123	124	124	123	122	120	118	117	116
2.60	A	154	* 0	#156	150	147	146	146	145	144	143	141	142	142	140	138	137	136	134	132	130	128
4.80	B	158	* 0	* 0	$ 0	156	156	156	154	151	150	149	148	147	147	145	144	143	142	141	140	141
5.95	C	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	*163	#160	159	158	157	156	154	153	151	150
2.95	D	* 0	142	140	139	138	136	134	132	131	130	130	129	129	129	127	125	124	123	123	123	122

Table 2.18

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(50, 13, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	122	123	118	115	111	109	108	107	107	106	104	102	101	99	98	97	96	96	95	94	93
1.00	W	141	134	142	132	130	126	123	120	119	118	117	116	114	113	112	112	110	110	110	109	108
0.20	X	110	106	106	103	105	108	110	111	108	104	101	100	100	100	98	98	96	93	92	92	92
0.45	X	132	129	122	119	118	117	117	116	117	118	116	115	114	111	109	109	109	109	109	107	106
1.00	X	139	132	132	132	130	130	128	126	127	128	127	123	121	121	121	120	118	117	117	118	116
0.10	Y	96	95	89	85	84	83	84	85	86	86	84	84	84	83	82	82	83	83	83	82	80
0.45	Y	138	132	127	123	122	120	119	118	115	114	113	112	114	114	113	112	111	108	107	107	106
1.00	Y	148	146	136	133	130	129	127	126	126	125	123	121	119	117	115	114	114	114	114	113	111
1.50	Y	139	135	130	128	128	128	128	128	128	127	125	125	123	122	122	122	121	120	121	119	117
0.05	Z	65	65	69	67	63	60	59	60	59	55	53	52	52	53	53	53	53	54	55	59	60
0.20	Z	108	105	102	100	101	103	104	101	101	102	104	107	109	105	99	97	95	92	89	87	87
0.70	Z	147	128	127	129	127	124	124	123	122	123	122	121	120	118	117	117	117	116	113	112	111
1.50	Z	142	137	132	133	135	137	137	137	135	133	132	132	131	129	127	128	128	128	128	125	121
2.60	A	150	155	152	149	149	150	150	147	144	142	141	141	143	145	145	144	141	137	134	132	131
4.80	B	* 0	160	157	157	156	155	153	152	151	150	148	146	145	144	143	142	142	142	142	142	141
5.95	C	166	166	167	167	167	167	165	164	163	162	160	156	155	154	154	153	151	150	149	148	147
2.95	D	* 0	148	145	144	144	143	141	138	136	134	133	133	133	132	130	129	128	127	127	126	126

Table 2.19

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(50, 40, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	121	117	118	117	114	114	115	114	112	114	114	112	111	111	108	106	104	102	101	100	101
1.00	W	139	136	134	134	133	128	131	128	125	122	120	117	116	117	118	119	118	116	115	114	113
0.20	X	106	102	100	100	101	100	99	99	99	97	95	95	93	90	89	89	89	88	87	85	83
0.45	X	131	130	129	127	133	139	131	120	119	117	114	113	111	109	109	110	110	108	110	108	107
1.00	X	135	140	124	123	121	120	119	119	118	119	118	116	114	112	111	109	108	108	106	105	104
0.10	Y	92	82	77	74	73	72	71	70	71	71	71	71	71	71	70	68	66	65	65	64	64
0.45	Y	124	115	112	114	115	111	108	107	106	106	106	106	105	108	114	116	114	111	112	109	104
1.00	Y	140	137	127	126	124	121	119	118	116	116	115	113	111	110	108	107	107	105	104	104	104
1.50	Y	135	130	126	124	124	123	123	122	120	119	118	118	118	118	117	116	117	115	114	113	111
0.05	Z	86	88	62	60	60	58	56	57	56	57	57	59	61	62	62	61	60	60	60	59	58
0.20	Z	104	102	93	91	88	85	82	80	78	78	77	76	75	74	73	72	72	71	71	71	70
0.70	Z	118	114	114	114	113	111	110	109	107	106	104	103	103	102	102	101	100	99	98	98	98
1.50	Z	127	125	119	118	119	120	120	122	121	118	116	116	116	116	116	116	116	114	111	110	108
2.60	A	145	149	146	146	149	149	146	143	142	139	137	138	140	140	137	136	138	137	133	132	130
4.80	B	*164	151	149	148	148	147	147	145	144	142	141	141	139	138	136	136	137	135	134	136	135
5.95	C	156	160	159	156	154	156	156	155	154	151	147	145	142	139	137	136	135	134	133	131	130
2.95	D	152	140	133	132	131	129	128	126	125	126	124	123	122	121	121	119	117	116	115	115	114

Table 2.20

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$$L_b = F_L(50,\ 80,\ V,\ d,\ H_r)$$

DIST (MI)	LOC	8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
		RECEIVE HEIGHT (FEET)																				
0.45	W	122	119	112	110	107	105	104	104	103	101	100	99	98	96	94	94	93	92	92	91	90
1.00	W	132	129	127	124	120	118	116	114	112	111	110	108	106	105	104	104	103	101	100	99	100
0.20	X	102	97	88	87	85	85	84	84	84	84	83	81	78	75	74	73	73	72	72	71	70
0.45	X	122	129	116	112	108	106	106	109	107	105	102	99	96	94	93	92	91	89	88	88	87
1.C0	X	127	123	115	116	116	114	115	114	112	111	110	109	107	106	103	102	101	100	99	98	97
0.10	Y	87	77	75	74	74	74	74	73	72	72	71	68	66	64	63	62	61	60	59	58	57
0.45	Y	118	111	107	106	103	100	99	98	96	92	90	90	91	93	94	94	92	91	90	89	88
1.00	Y	134	129	123	123	120	117	115	113	114	116	114	110	108	107	105	104	104	103	102	100	99
1.50	Y	127	124	117	115	115	114	113	112	111	110	109	109	109	109	108	107	107	106	105	104	103
0.05	Z	65	63	71	66	62	60	57	56	54	54	54	55	56	54	52	52	50	49	48	47	47
0.20	Z	91	88	84	82	81	79	76	73	72	71	71	72	71	70	69	68	67	67	66	66	65
0.70	Z	109	108	109	109	108	107	105	103	101	100	99	98	97	96	96	95	94	93	91	90	89
1.50	Z	122	115	112	112	113	113	112	113	116	114	111	111	109	109	109	108	107	106	105	103	101
2.60	A	131	134	137	138	133	130	129	129	128	127	128	129	127	121	120	119	120	119	116	113	111
4.80	B	155	141	139	138	138	136	134	133	132	131	131	130	128	127	127	126	125	124	124	124	124
5.95	C	146	141	146	143	141	139	137	135	136	135	132	131	129	127	126	125	125	123	122	121	120
2.95	D	141	132	126	124	122	120	119	118	118	118	118	118	117	115	113	111	110	109	108	108	107

Table 2.21

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(50, 120, V, d, H_r)$

DIST (MI)	LOC	8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
		RECEIVE HEIGHT (FEET)																				
0.45	W	101	99	105	103	100	96	93	92	92	91	89	86	83	82	80	80	79	79	78	78	77
1.00	W	122	114	109	107	105	103	101	98	96	95	93	92	91	90	88	87	86	85	84	84	84
0.20	X	89	83	79	77	77	78	78	78	78	76	75	72	70	68	67	66	65	65	64	63	62
0.45	X	113	120	103	100	97	95	94	94	90	88	86	85	84	83	81	81	79	78	78	77	77
1.00	X	116	108	105	106	105	103	103	104	106	104	101	99	97	95	93	91	90	90	89	88	87
0.10	Y	82	72	69	68	68	68	67	64	61	60	58	57	56	56	55	55	54	56	56	56	56
0.45	Y	115	106	115	113	112	107	90	87	87	85	83	83	84	85	84	84	82	81	81	80	80
1.00	Y	120	117	110	109	109	109	109	106	103	102	101	100	100	98	96	94	93	92	91	90	89
1.50	Y	118	114	109	108	108	108	107	106	104	103	102	101	100	100	100	99	99	98	97	95	95
0.05	Z	61	59	59	58	56	55	58	58	55	55	55	53	51	50	49	48	47	47	46	46	46
0.20	Z	83	80	79	78	77	76	73	70	69	69	69	68	66	65	64	63	62	62	62	62	61
0.70	Z	102	102	103	105	103	100	99	98	95	93	92	91	91	90	89	88	88	88	86	84	83
1.50	Z	114	112	104	104	105	104	105	107	107	105	103	103	103	102	101	100	99	98	97	95	93
2.60	A	124	128	127	124	121	119	120	119	117	115	115	117	121	123	121	117	113	110	106	103	102
4.80	B	145	134	131	131	131	130	129	127	126	124	123	123	122	121	120	119	118	118	117	116	116
5.95	C	140	134	141	137	134	133	131	128	130	129	125	123	122	121	119	118	117	116	115	114	113
2.95	D	128	125	117	115	114	112	112	112	112	113	112	111	110	107	104	102	101	100	99	98	98

Table 2.22

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(50, 13, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	106	103	97	94	92	91	90	91	92	92	92	92	92	92	90	87	85	84	83	82	81
1.00	W	118	114	113	112	111	110	110	109	108	107	107	106	105	105	105	104	104	103	103	103	102
0.20	X	100	85	84	84	82	81	80	79	78	79	80	80	78	76	76	75	74	74	74	75	75
0.45	X	111	102	100	99	99	101	102	102	101	100	98	98	97	95	95	95	94	93	92	92	91
1.00	X	114	116	115	114	112	111	110	109	110	110	109	109	109	109	108	106	105	104	103	102	102
0.10	Y	75	87	75	72	70	70	67	63	62	63	63	63	61	59	58	56	54	54	54	54	54
0.45	Y	110	112	116	117	113	109	106	105	103	101	100	98	97	97	97	96	96	95	95	94	93
1.00	Y	133	122	11[illegible]	116	115	113	112	113	113	115	116	114	111	109	107	106	105	104	105	105	104
1.50	Y	132	126	124	124	125	125	125	125	124	124	125	124	124	123	123	122	121	120	120	119	117
0.05	Z	60	52	51	48	47	46	45	43	43	44	43	43	43	43	43	43	43	43	43	44	49
0.20	Z	90	90	86	83	83	83	77	80	77	75	74	71	69	67	66	65	64	63	63	63	62
0.70	Z	120	110	121	122	114	112	109	107	106	104	103	102	101	99	98	97	96	96	95	95	95
1.50	Z	118	114	123	120	118	119	120	120	118	117	118	119	118	117	116	115	118	118	114	112	110
2.60	A	129	123	121	120	119	119	121	125	128	128	126	125	125	126	124	122	120	118	117	116	114
4.80	B	*162	151	147	144	142	142	141	141	140	140	139	139	138	138	136	134	133	133	134	134	132
5.95	C	151	152	148	145	142	140	141	142	140	139	139	139	138	137	135	133	132	131	130	130	129
2.95	D	140	140	133	132	131	131	13[illegible]	130	129	128	127	127	126	126	125	125	125	124	123	123	123

Table 2.23

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(50, 40, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	106	96	92	91	88	87	87	87	86	86	86	86	85	84	82	81	80	79	78	77	76
1.00	W	107	105	104	103	102	100	100	99	98	97	96	95	95	94	93	92	92	92	91	91	91
0.20	X	92	84	85	88	87	84	82	80	78	76	76	72	71	73	73	71	70	69	69	68	68
0.45	X	105	95	92	92	92	93	95	95	92	91	90	90	89	88	87	87	86	84	84	83	83
1.00	X	109	110	109	108	106	104	103	103	109	104	103	103	103	103	102	101	100	99	97	96	95
0.10	Y	69	66	62	58	57	55	54	54	53	53	53	53	53	53	54	54	55	56	57	59	60
0.45	Y	104	99	99	98	96	94	93	93	93	92	91	92	92	91	89	88	87	86	85	85	85
1.00	Y	127	114	108	106	104	103	102	102	103	104	104	104	102	101	99	97	96	95	95	94	94
1.50	Y	121	112	110	109	109	110	111	111	111	112	111	112	110	110	110	108	106	105	105	104	103
0.05	Z	53	48	45	43	43	43	44	46	48	50	56	59	55	52	50	48	47	45	45	45	45
0.20	Z	84	80	75	72	71	71	71	70	69	69	68	66	66	65	65	64	64	64	64	65	66
0.70	Z	120	109	109	114	115	110	109	108	106	105	104	102	100	99	98	97	96	95	94	94	93
1.50	Z	117	119	121	122	120	118	118	119	119	117	116	117	116	114	114	114	115	114	112	109	108
2.60	A	128	122	120	120	119	118	121	124	125	125	123	123	123	124	125	124	121	118	115	113	112
4.80	B	148	141	134	131	130	130	130	130	129	128	128	127	126	126	125	124	123	123	123	122	121
5.95	C	143	142	140	138	136	135	135	135	134	134	133	132	132	131	130	128	127	125	124	123	122
2.95	D	127	125	119	118	117	117	116	115	115	114	114	113	113	113	112	112	112	112	111	110	109

Table 2.24

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(50, 80, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	105	106	95	92	89	87	86	87	86	85	85	85	84	83	81	81	81	79	78	77	77
1.00	W	113	111	107	107	106	104	104	104	103	101	101	100	99	98	98	97	96	96	96	95	94
0.20	X	81	77	76	76	77	79	78	76	75	74	73	71	71	70	70	70	70	70	70	70	70
0.45	X	102	93	90	89	89	90	91	91	90	88	88	88	87	86	85	85	85	84	83	83	82
1.00	X	109	109	108	107	105	103	102	102	103	103	102	102	102	102	102	101	100	99	98	96	94
0.10	Y	60	57	53	53	53	53	53	54	55	55	55	57	61	70	70	60	57	55	54	54	54
0.45	Y	105	100	100	100	99	97	95	94	93	92	91	90	90	90	89	89	88	87	87	87	87
1.00	Y	129	115	110	108	106	105	104	104	104	105	105	104	103	101	99	98	97	96	95	95	95
1.50	Y	118	112	110	109	110	111	111	108	109	110	111	110	110	109	108	107	105	105	103	103	102
0.05	Z	52	46	45	46	50	55	55	49	45	44	45	48	52	55	51	46	44	44	45	48	51
C.20	Z	91	81	67	64	65	66	65	65	65	67	70	71	71	69	67	65	63	62	62	62	61
0.70	Z	113	107	112	114	108	107	105	102	101	100	98	97	96	94	93	93	92	92	91	91	91
1.50	Z	110	112	112	113	113	111	111	110	110	109	109	110	109	108	107	107	107	107	105	102	100
2.60	A	122	116	114	113	112	112	113	116	119	119	118	117	117	116	116	115	113	112	110	108	107
4.80	B	148	141	135	132	131	131	131	130	130	129	128	128	127	127	125	124	122	121	120	120	120
5.95	C	143	146	141	138	134	132	132	132	132	131	130	129	129	128	127	125	122	121	121	120	120
2.95	D	122	121	114	113	112	112	112	111	110	109	108	108	108	108	107	106	106	105	104	104	103

Table 2.25

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(50, 120, H, d, H_r)$

DIST (MI)	LOC	8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
		RECEIVE HEIGHT (FEET)																				
0.45	W	94	89	88	84	82	81	81	81	81	81	82	83	84	83	81	79	77	76	75	73	73
1.00	W	104	101	99	99	98	97	96	96	96	94	92	91	90	90	90	90	88	86	86	86	85
0.20	X	74	70	67	66	67	69	69	69	71	73	74	74	73	71	68	66	65	64	63	61	61
0.45	X	94	84	83	82	83	84	85	85	83	82	82	82	81	80	80	81	80	79	78	77	76
1.00	X	101	102	101	100	98	97	95	95	96	96	96	95	95	94	93	92	92	90	89	89	88
0.10	Y	58	57	54	54	55	57	60	61	68	61	55	52	52	53	56	60	61	59	55	53	54
0.45	Y	96	91	91	91	89	86	85	84	84	83	82	82	82	82	81	80	79	79	79	79	78
1.00	Y	121	110	105	102	101	100	99	98	99	100	100	100	98	95	93	92	92	91	91	91	90
1.50	Y	111	105	102	102	102	102	103	103	103	103	103	102	102	101	101	100	98	97	96	95	94
0.05	Z	49	46	48	59	53	48	49	52	57	54	50	50	55	56	52	49	47	49	50	49	46
0.20	Z	77	68	64	62	62	63	63	64	66	70	69	65	63	61	60	59	59	59	60	60	59
0.70	Z	104	97	103	104	99	98	96	93	92	91	89	88	87	86	84	83	83	82	82	82	82
1.50	Z	103	105	106	107	106	103	102	102	103	102	102	102	102	101	101	101	100	100	98	95	93
2.60	A	116	109	108	107	107	108	110	113	115	114	111	111	111	111	111	111	108	105	103	101	100
4.80	B	139	133	127	124	123	122	122	121	121	120	119	119	118	118	117	116	115	114	114	113	113
5.95	C	140	139	134	131	128	126	126	125	125	125	124	124	123	122	121	119	118	116	115	114	113
2.95	D	118	117	110	109	108	107	106	106	106	105	104	104	104	103	103	103	102	102	101	100	100

Table 2.26

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(100, 13, V, d, H_r)$

DIST (MI)	LOC	8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
		RECEIVE HEIGHT (FEET)																				
0.45	W	123	123	123	124	121	117	116	114	114	113	111	109	106	104	103	105	107	105	104	104	102
1.00	W	*146	141	136	132	132	131	128	128	129	128	126	123	121	119	118	115	113	113	114	113	111
0.20	X	116	113	108	103	103	102	101	103	108	107	101	101	99	98	97	95	92	92	90	87	88
0.45	X	145	126	129	129	126	126	124	134	121	123	118	117	114	109	107	105	104	103	102	102	101
1.00	X	138	139	138	140	134	135	137	134	140	132	129	127	125	122	119	117	116	115	114	113	113
0.10	Y	98	103	92	88	88	82	80	82	86	91	101	94	86	89	84	83	84	91	86	91	86
0.45	Y	*145	130	129	129	126	125	129	130	126	125	125	126	124	124	121	124	124	124	118	118	115
1.00	Y	* 0	* 0	*143	*143	#142	141	137	13[illegible]	134	132	130	128	126	127	124	120	119	121	120	118	117
1.50	Y	148	* 0	$ 0	143	142	136	136	137	137	139	139	138	136	133	132	132	132	132	133	130	128
0.05	Z	67	69	65	62	59	56	54	55	56	54	53	53	53	53	53	53	52	52	53	53	54
0.20	Z	117	114	110	103	99	99	98	97	100	103	100	97	93	93	94	89	87	85	85	84	82
0.70	Z	150	141	142	140	137	139	133	133	130	126	127	128	127	127	124	128	125	123	124	123	119
1.50	Z	* 0	*138	*139	*139	$ 0	* 0	$ 0	#137	130	126	126	129	132	131	128	127	128	127	124	122	121
2.60	A	*158	* 0	$ 0	#154	#152	147	144	142	140	139	140	141	143	143	141	140	137	134	133	131	130
4.80	B	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	#156	153	152	151	149	148	147	147	145	144	144	144	144
5.95	C	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	#154	151	149	148	147	145	143	143	143	140
2.95	D	* 0	* 0	* 0	* 0	$ 0	#140	138	137	136	137	137	137	137	137	137	136	134	132	130	130	129

Table 2.27

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(100, 80, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	120	120	119	121	121	122	121	118	115	114	111	108	106	105	104	103	102	101	100	98	95
1.00	W	136	136	135	136	137	133	126	122	120	119	117	115	114	111	109	109	109	108	106	106	107
0.20	X	108	100	102	108	106	99	96	96	92	90	90	89	88	85	84	83	82	81	82	82	83
0.45	X	124	133	118	116	113	109	108	109	108	104	104	103	100	98	97	94	93	92	92	92	92
1.00	X	122	123	125	121	120	119	120	123	121	119	114	113	112	109	105	104	102	100	100	100	97
0.10	Y	80	79	76	77	81	83	82	89	90	87	93	95	82	82	78	81	85	85	83	78	80
0.45	Y	124	125	123	124	124	119	114	112	110	108	107	107	107	107	107	110	112	112	111	109	107
1.00	Y	139	131	134	#142	#142	134	131	130	124	119	117	115	112	109	109	108	108	107	106	105	105
1.50	Y	147	134	131	131	127	123	121	121	121	121	123	122	121	118	116	115	113	115	115	113	112
0.05	Z	69	68	75	72	69	69	69	74	64	55	56	60	60	59	58	56	56	53	52	52	51
0.20	Z	95	88	92	90	90	95	95	89	88	87	83	81	80	77	75	73	72	72	72	72	70
0.70	Z	129	129	131	128	128	125	130	120	118	114	114	114	114	112	108	108	108	104	103	102	100
1.50	Z	129	126	126	126	123	120	124	122	118	117	115	112	110	111	111	112	114	112	107	105	103
2.60	A	145	147	144	143	140	137	134	130	129	130	132	133	132	130	129	129	128	125	123	119	116
4.80	B	* 0	* 0	*159	#156	153	150	147	149	145	142	145	145	141	137	137	138	135	131	132	132	129
5.95	C	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	$ 0	* 0	* 0	$ 0	150	149	149	145	142
2.95	D	138	* 0	* 0	$ 0	135	134	131	129	130	129	125	123	122	123	123	121	120	120	120	119	118

Table 2.28

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(100,\ 120,\ V,\ d,\ H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	116	123	105	1C7	108	106	107	107	103	100	99	99	97	92	90	90	89	87	85	84	83
1.00	W	124	122	120	118	118	117	114	111	109	107	104	102	101	99	98	97	96	95	94	92	92
0.20	X	95	93	93	92	88	86	84	81	84	83	83	85	83	80	82	79	74	72	71	69	68
0.45	X	112	114	110	106	104	122	99	98	98	95	95	95	94	91	91	89	87	86	86	84	83
1.00	X	111	115	113	112	110	111	118	115	112	106	105	104	103	101	97	94	95	94	92	91	89
0.10	Y	68	78	83	79	76	73	73	75	81	74	72	69	66	66	65	63	62	62	62	61	59
0.45	Y	111	107	106	105	106	108	105	101	98	96	94	93	93	93	90	87	86	85	84	83	84
1.00	Y	126	118	120	121	119	119	118	117	114	109	106	104	101	99	98	97	95	93	93	95	93
1.50	Y	133	120	119	119	114	110	111	112	113	111	114	117	114	110	107	105	105	104	103	101	101
0.05	Z	57	69	60	62	62	63	61	59	57	58	57	54	55	55	54	52	50	50	51	49	48
C.20	Z	94	90	82	80	83	84	79	75	75	74	73	72	72	70	66	65	65	65	65	63	62
C.70	Z	115	115	119	117	115	116	114	110	104	103	103	103	100	98	99	100	98	96	94	92	91
1.50	Z	117	112	115	113	119	119	110	110	111	110	109	105	101	101	100	101	102	98	95	93	91
2.60	A	136	132	134	132	128	124	123	120	120	124	125	127	121	118	115	115	114	110	107	106	105
4.80	B	155	150	148	145	142	141	140	135	131	130	129	128	127	125	124	124	124	124	124	122	122
5.95	C	152	153	151	148	147	145	147	149	144	141	137	133	132	134	133	131	128	127	125	123	122
2.95	D	128	132	131	126	123	123	120	116	117	117	116	113	110	111	112	111	109	107	106	106	105

Table 2.29

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(100, 13, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	115	113	110	110	110	109	108	109	110	109	107	106	104	105	105	104	101	98	98	98	98
1.00	W	135	129	125	125	125	125	124	122	120	118	118	118	118	115	113	112	111	111	110	109	108
0.20	X	85	85	88	88	91	94	95	95	91	89	87	87	87	87	85	81	79	78	77	77	77
0.45	X	112	113	118	120	113	115	114	114	113	110	107	107	106	104	103	102	99	98	98	97	96
1.00	X	128	127	126	128	126	129	126	129	124	127	122	119	120	120	119	117	114	112	114	113	111
0.10	Y	75	73	72	71	70	68	69	69	70	74	88	84	93	75	74	72	71	69	66	65	65
0.45	Y	119	124	117	115	112	112	116	117	114	113	111	110	109	108	108	106	103	102	100	99	97
1.00	Y	133	129	136	137	136	137	144	145	138	139	139	133	130	127	124	121	120	120	120	120	119
1.50	Y	139	127	128	127	125	123	123	125	125	123	123	123	122	120	119	119	117	116	115	114	113
0.05	Z	64	48	47	47	47	47	45	45	47	49	52	55	55	56	61	65	63	58	55	50	48
0.20	Z	94	89	83	83	84	87	88	87	87	87	88	90	88	83	78	76	75	74	73	73	73
0.70	Z	133	123	139	136	133	134	130	127	124	121	119	120	119	117	116	116	116	115	114	113	112
1.50	Z	130	133	133	#138	#137	134	134	132	128	125	125	124	124	125	125	124	122	120	121	120	115
2.60	A	143	146	143	141	139	138	138	138	138	138	139	141	146	143	136	134	133	130	128	127	125
4.80	B	140	147	147	146	144	143	142	142	142	140	138	137	136	134	134	134	134	134	134	134	134
5.95	C	161	150	153	155	153	150	150	150	150	149	146	143	143	143	142	140	139	138	137	136	135
2.95	D	*143	* 0	$ 0	* 0	$ 0	*144	#143	140	139	#141	*144	#142	139	138	138	139	138	136	134	132	132

Table 2.30

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(100, 80, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	112	113	111	110	107	105	103	103	104	106	107	106	105	103	101	99	98	96	95	94	92
1.00	W	127	122	118	117	115	115	116	115	114	113	112	111	109	107	106	105	104	103	103	102	101
0.20	X	94	96	100	103	110	97	90	88	90	90	92	93	93	91	89	87	84	83	84	83	83
0.45	X	110	110	110	111	112	111	113	111	110	108	106	104	102	101	101	99	97	97	97	95	94
1.00	X	113	107	113	107	106	107	107	106	107	105	103	103	101	98	96	94	92	91	91	90	90
0.10	Y	70	63	64	70	79	78	77	71	69	72	75	82	73	74	71	66	68	69	72	73	73
0.45	Y	117	124	114	109	107	106	106	106	108	105	100	99	102	102	101	99	96	96	95	94	93
1.00	Y	128	118	127	135	135	132	128	124	123	120	116	115	112	110	108	107	107	105	103	103	102
1.50	Y	142	123	125	124	121	121	121	123	123	124	125	126	125	122	119	117	115	114	113	112	110
0.05	Z	51	53	62	51	50	56	54	51	54	59	59	55	57	57	54	51	58	59	51	50	53
0.20	Z	84	82	79	79	83	88	87	84	81	79	77	78	78	77	76	75	74	73	73	73	72
0.70	Z	129	117	131	137	132	123	122	117	113	112	112	112	111	110	109	108	108	107	106	106	104
1.50	Z	124	124	126	127	128	129	126	124	124	120	119	117	115	114	116	118	116	113	112	111	107
2.60	A	140	137	142	141	137	134	134	134	136	135	136	136	133	133	133	132	129	125	124	121	119
4.80	B	152	147	148	147	145	144	142	142	141	139	138	137	136	135	134	133	133	134	134	133	133
5.95	C	153	148	151	153	151	149	148	149	150	150	149	147	145	145	144	141	139	138	137	136	134
2.95	D	136	136	141	140	136	134	132	131	130	130	131	130	127	126	126	125	123	121	120	119	118

Table 2.31

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(100, 120, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	95	96	96	96	97	98	97	96	96	95	94	92	90	86	86	86	86	84	83	82	81
1.00	W	117	110	108	107	107	106	106	106	106	105	102	100	99	96	94	94	93	93	92	91	90
0.20	X	82	82	87	85	81	80	80	81	82	84	82	79	78	77	77	76	75	74	73	73	72
0.45	X	98	100	101	102	100	99	98	99	98	95	92	91	90	89	87	86	85	84	83	83	82
1.00	X	104	100	106	102	99	101	104	98	96	96	95	93	93	92	89	87	86	85	84	84	83
0.10	Y	69	71	75	84	74	69	66	75	76	75	73	70	71	70	67	67	68	66	64	63	63
0.45	Y	113	111	113	103	97	100	97	98	95	92	91	91	90	90	89	89	88	86	85	83	81
1.00	Y	111	107	114	121	120	118	118	112	107	105	104	103	100	98	97	96	94	93	92	91	90
1.50	Y	125	111	113	112	110	109	112	112	111	109	110	110	108	107	107	106	104	104	102	100	100
0.05	Z	51	64	52	55	53	57	56	53	56	52	56	53	53	56	52	53	53	51	52	49	47
0.20	Z	87	77	79	80	77	74	72	74	74	74	73	69	68	67	68	68	66	66	66	65	65
0.70	Z	115	109	116	118	113	114	114	109	104	102	101	100	99	98	97	96	96	95	94	93	92
1.50	Z	109	118	115	118	116	114	114	109	108	110	110	105	102	103	104	103	101	99	97	95	92
2.60	A	126	127	129	129	127	122	122	121	123	124	126	125	121	120	120	119	116	113	112	109	107
4.80	B	140	135	136	135	133	132	130	129	129	127	126	125	124	123	123	123	122	122	121	121	122
5.95	C	142	137	140	144	143	139	138	138	137	137	135	134	133	132	131	129	128	127	126	124	123
2.95	D	139	124	124	124	124	122	119	117	118	120	117	114	114	114	113	113	111	110	109	109	107

Table 2.32

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(250, 13, V, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	136	135	132	132	133	135	133	130	129	125	123	123	124	122	120	116	112	109	105	104	103
1.00	W	*139	*139	*139	*139	*139	*139	#137	135	135	135	134	131	127	123	125	126	121	117	113	109	109
0.20	X	120	120	117	114	117	112	111	110	111	110	106	102	110	108	108	106	105	101	102	101	100
0.45	X	141	133	141	145	143	135	140	142	131	139	127	135	135	128	123	119	117	114	112	110	107
1.00	X	*0	*0	$0	#141	$0	*0	$0	#142	#141	#143	*145	#139	136	136	136	133	130	127	121	124	121
0.10	Y	96	94	93	93	96	100	93	93	94	91	88	84	88	88	99	102	96	91	89	88	92
0.45	Y	136	137	136	140	$0	135	136	136	135	$0	134	134	132	133	136	135	136	134	130	125	119
1.00	Y	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	$0	#134	133	131	130	$0	$0	130	126	124
1.50	Y	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	$0	*0	$0	*0	$0	*0	$0	$0	139	133	131
0.05	Z	75	66	70	69	71	74	76	77	82	82	82	81	82	71	68	72	73	67	66	67	67
0.20	Z	111	119	112	111	108	110	113	111	109	110	107	104	103	102	102	103	100	98	100	98	95
0.70	Z	*0	*0	*0	$0	$0	$0	$0	$0	$0	$0	$0	$0	#142	#139	135	#140	$0	$0	136	132	129
1.50	Z	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	$0	*138	*137	*138	*138	*138	*138	#135
2.60	A	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	$0	*0	*0	*0	$0	#148	#148	$0	#147	141
4.80	B	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0
5.90	C	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0
2.95	D	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	*0	$0	#133	131	#133	#132	130	130	128	126	125

Table 2.33

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(250,\ 120,\ V,\ d,\ H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	123	130	123	122	119	114	112	110	110	113	114	113	108	100	99	99	98	96	95	94	97
1.00	W	* 0	* 0	$ 0	#132	129	127	127	#131	#132	125	119	117	115	114	115	114	113	112	109	107	106
0.20	X	101	96	98	97	97	92	95	96	100	96	88	84	85	86	85	85	84	78	77	76	76
0.45	X	123	118	123	111	123	121	109	107	109	110	118	118	104	104	105	107	95	92	91	89	88
1.00	X	126	127	131	129	128	123	124	127	123	124	119	119	122	118	119	110	105	102	99	99	98
0.10	Y	89	80	81	80	79	79	80	80	78	83	84	86	87	83	78	75	77	78	75	70	67
0.45	Y	114	111	112	113	110	112	105	112	114	111	111	100	96	98	99	99	99	94	90	92	93
1.00	Y	128	125	128	122	122	121	121	125	123	116	114	110	106	105	106	104	103	104	103	102	101
1.50	Y	130	134	131	131	131	130	131	127	125	126	122	117	116	116	118	116	112	111	111	113	108
0.05	Z	77	72	81	76	70	72	71	75	64	65	64	66	70	64	59	58	58	57	57	56	57
0.20	Z	93	90	93	93	94	85	89	92	91	85	94	91	76	76	74	72	71	70	70	70	71
0.70	Z	130	126	125	127	123	123	124	124	123	118	119	118	117	116	117	114	115	115	111	108	104
1.50	Z	129	*135	127	#130	#130	127	129	130	126	122	119	115	115	117	114	110	109	108	109	107	102
2.60	A	139	*148	137	#141	$ 0	$ 0	$ 0	$ 0	$ 0	137	138	$ 0	$ 0	137	134	132	126	120	123	120	114
4.80	B	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	*145	*145	#142	138	137	138	140	137	134	136	134	131
5.95	C	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	$ 0	$ 0	143	140	142
2.95	O	* 0	*131	$ 0	* 0	$ 0	#131	127	126	125	121	119	118	117	118	117	114	110	109	109	109	108

Table 2.34

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(250, 13, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	125	116	124	125	127	126	121	122	122	120	120	121	115	111	109	107	105	105	104	103	104
1.00	W	* 0	* 0	* 0	* 0	$ 0	*130	*130	*130	*130	*129	*128	#126	123	122	120	118	117	117	117	116	115
0.20	X	113	107	109	110	111	110	110	104	102	101	102	99	102	104	102	101	97	95	93	90	86
0.45	X	* 0	*129	* 0	* 0	* 0	* 0	$ 0	#127	125	124	123	122	121	119	118	117	115	114	112	110	110
1.00	X	142	141	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	142	139	137	:32	134	130	128	128	128	124	121	118	119
0.10	Y	78	90	85	89	87	74	78	78	78	79	80	78	81	87	81	83	92	82	86	95	88
0.45	Y	130	138	129	135	133	126	128	130	136	133	127	121	120	119	119	117	117	116	114	113	111
1.00	Y	* 0	* 0	* 0	* 0	* 0	$ 0	$ 0	$ 0	140	140	139	135	132	129	126	125	130	130	127	127	125
1.50	Y	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	$ 0	$ 0	#147	$ 0	$ 0	$ 0	$ 0	$ 0	143	141	141	138	138	136
0.05	Z	62	54	57	60	60	66	72	61	57	56	59	64	60	65	65	62	60	58	59	60	61
0.20	Z	100	99	98	100	99	97	102	106	103	99	96	97	98	100	100	95	90	88	87	86	85
0.70	Z	* 0	142	#143	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	139	138	138	$ 0	$ 0	$ 0	135	131	132	129	128	128
1.50	Z	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	$ 0	$ 0	$ 0	$ 0	*138	*137	#135	131	128
2.60	A	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	142	141	:41	142	139	135
4.80	B	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0
5.90	C	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0
2.95	D	* 0	* 0	* 0	* 0	$ 0	*137	*137	*135	#132	131	.31	130	130	130	127	124	122	120	119	118	117

Table 2.35

BASIC TRANSMISSION LOSS FROM HEIGHT-GAIN MEASUREMENTS

$L_b = F_L(250, 120, H, d, H_r)$

DIST (MI)	LOC	RECEIVE HEIGHT (FEET) 8	15	23	28	34	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
0.45	W	123	108	117	118	116	114	116	110	107	105	103	103	100	95	94	91	90	88	86	87	87
1.00	W	* 0	* 0	*127	*127	$ 0	$ 0	*128	#125	122	119	117	116	115	113	106	110	108	108	108	107	107
0.20	X	90	102	99	96	91	97	98	91	92	91	86	91	92	86	84	84	81	75	75	74	74
0.45	X	121	115	116	118	117	117	118	115	112	107	106	104	99	97	94	92	91	90	90	89	87
1.00	X	118	120	121	121	121	120	120	122	121	121	114	113	111	108	106	106	104	102	98	96	95
0.10	Y	79	72	73	77	81	79	80	82	82	81	79	76	74	71	70	70	72	71	68	67	65
0.45	Y	105	109	108	108	104	101	103	107	105	105	102	99	93	92	93	93	92	91	91	90	92
1.00	Y	110	114	117	117	117	118	117	116	118	114	108	107	104	102	100	99	98	98	99	98	98
1.50	Y	129	126	130	128	132	131	128	121	120	120	121	116	113	114	114	113	111	110	110	108	107
0.05	Z	61	65	63	63	63	65	72	73	65	65	63	62	64	61	57	58	59	55	56	55	55
0.20	Z	85	87	87	90	97	96	84	84	84	85	83	81	79	77	75	74	74	74	75	75	74
0.70	Z	117	118	129	124	125	126	116	121	114	114	110	112	111	108	106	106	104	102	103	100	98
1.50	Z	123	124	128	128	122	116	116	117	117	115	113	111	110	115	116	116	115	109	107	104	100
2.60	A	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ G	$ 0	$ 0	$ 0	#132	130	126	#130	127	123	119	119	117	114	110
4.80	B	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	#142	135	131	134	136	133	136	135	131	130
5.95	C	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	* 0	$ 0	*149	#147	143	140	140	142	141	140	139	138
2.95	D	*132	127	126	124	126	#130	#129	128	127	123	119	118	118	117	116	113	111	109	107	106	105

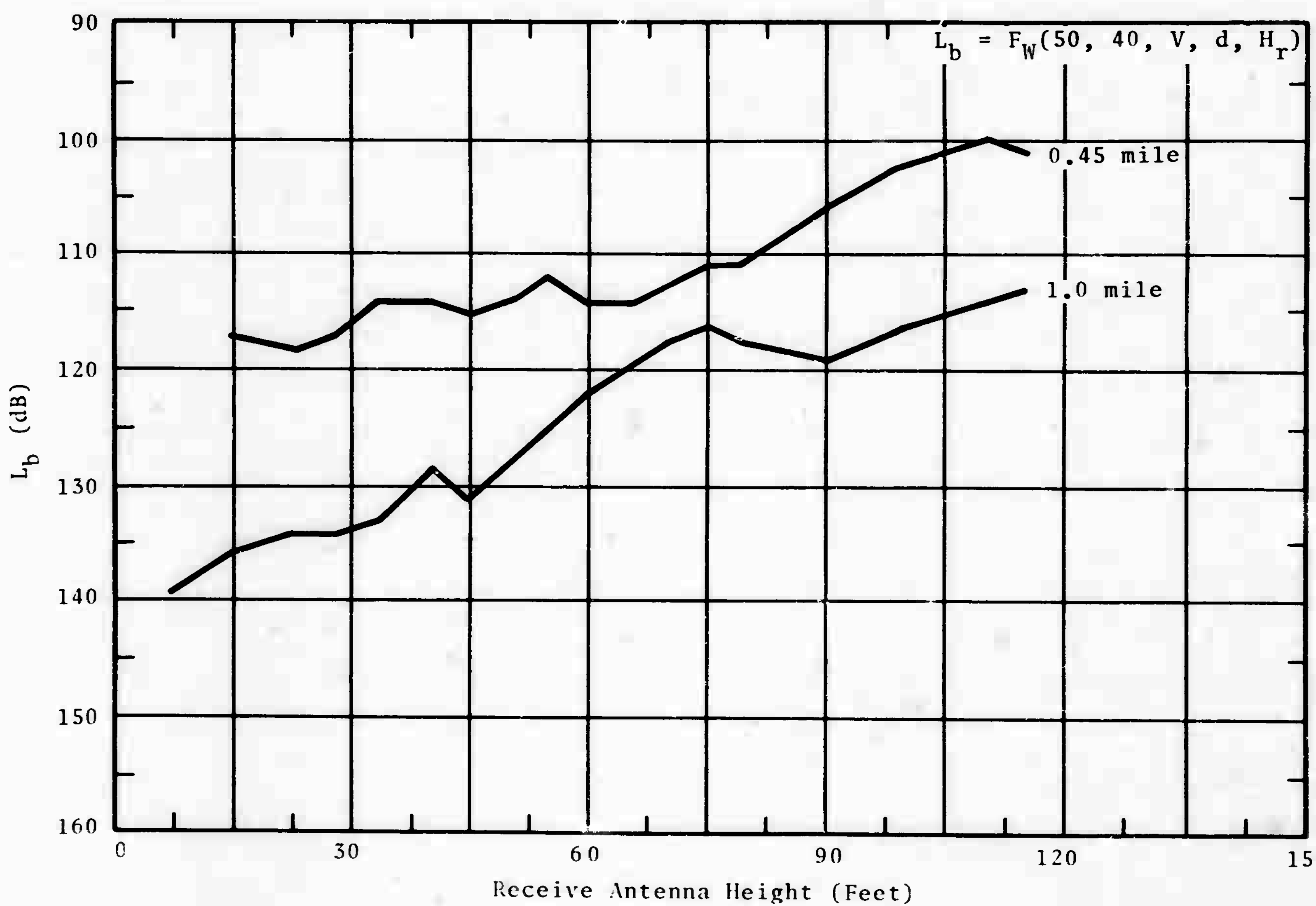

Figure 2.3 Variation of Basic Transmission Loss with Receive Antenna Height

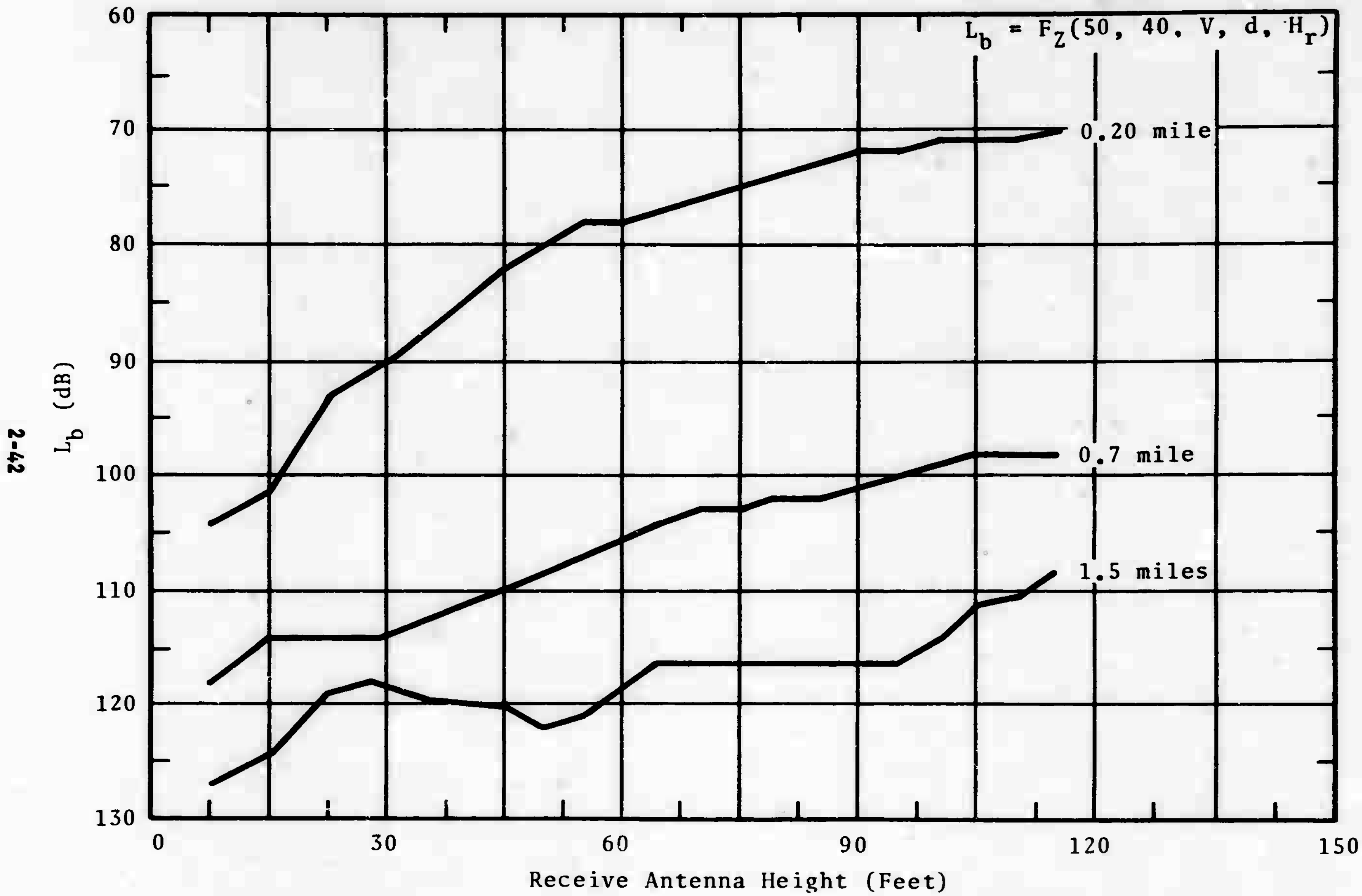

Figure 2.4 Variation of Basic Transmission Loss with Receive Antenna Height

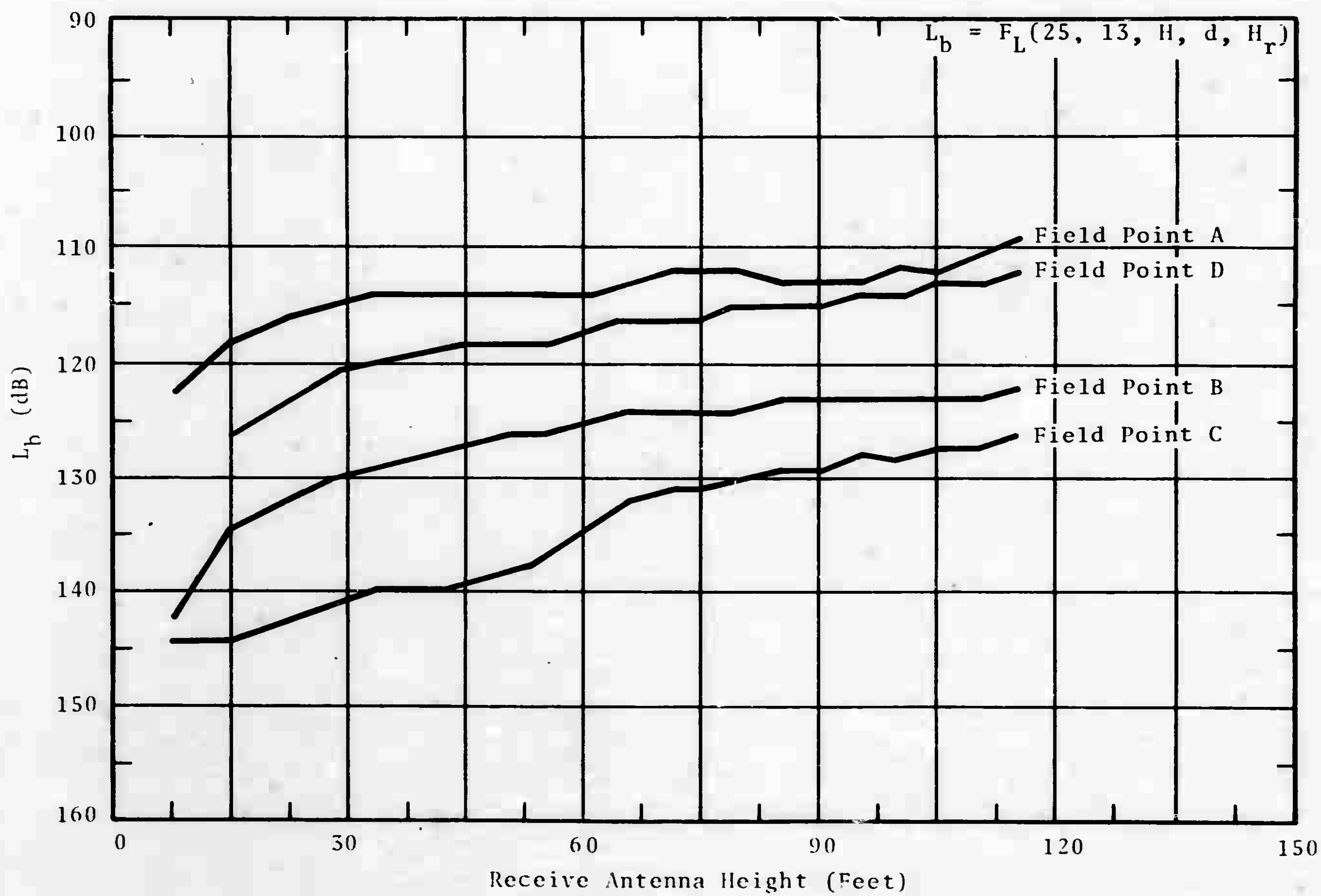

Figure 2.5 Variation of Basic Transmission Loss with Receive Antenna Height

The tabular form of data presentation was chosen because it provides the most compact form of presenting all the measured data. Also, if desired, the various effects of intervening terrain and any singularities which might occur at any onc measurement location may be observed by examining the distance dependence of basic transmission loss for a particular trail system or other various combinations of the data. Illustrating this last point are Figures 2.3, 2.4, and 2.5. These figures present basic transmission loss as a function of receive antenna height with distance as a varying parameter. Figures 2.3 and 2.4 show the data taken on radials W and Z at 50 Mc/s with a transmitting antenna height of 40 feet and vertical polarization. Detailed terrain profiles for these points are in the previous semiannual report.[3] Figure 2.5 presents the measurements made at the fixed field points A, B, C, and D for 25 Mc/s with a transmitting antenna height of 13 feet and horizontal polarization.

2.3 Average Height Gain

Because Tables 2.3 through 2.35 present the data obtained at the Area II measurement site in such detail, they have the tendency to mask out general data trends. For any type of general data analysis it becomes necessary to bring these general data trends to the fore. The first step taken in illuminating these general trends is to examine the data for the 40 times the logarithm of antenna separation distance in miles (40 log d) dependence that had been indicated by the Area I measurements and the Area II walking measurements.

This process consisted of normalizing to 1 mile all of the data points presented in Tables 2.3 through 2.35 by factoring out the expected distance dependence from each data point. Then, each column of normalized values was averaged to obtain the mean basic transmission loss normalized to 1 mile for a particular transmit antenna configuration and receive antenna height. Using this mean and the sample range just established, a standard deviation was computed. Sample results from three sets of averaged data are shown in Table 2.36. Presented in the table are the average value, the sample range, and the standard deviation for a set of normalized 1 mile path losses associated with a particular transmit and receive antenna configuration. All units in the table are decibels unless otherwise stated.

Examination of Table 2.36 reveals that the standard deviation generally increases as the height of the receive antenna decreases. The small differences existing

Table 2.36

SAMPLE ANALYSIS OF 40 LOG d_{mi} DATA DEPENDENCE

	Receive Antenna Height in Feet										
	8	23	34	45	55	65	75	85	95	105	115
					$F_L(25, 13, V, 1.0, H_r)$						
Average Value at 1.0 Mile	131	128	124	120	119	117	116	114	112	111	110
Sample Range	112 to 141	113 to 137	109 to 132	106 to 129	106 to 129	106 to 127	106 to 128	103 to 126	101 to 122	100 to 119	99 to 120
Standard Deviation	8.41	7.39	6.73	6.83	6.85	6.75	6.75	6.91	5.93	5.52	5.61
					$F_L(50, 80, H, 1.0, H_r)$						
Average Value at 1.0 Mile	112	105	103	102	101	100	100	99	96	95	94
Sample Range	100 to 129	93 to 118	93 to 114	93 to 111	91 to 107	90 to 105	90 to 104	88 to 110	88 to 102	86 to 101	85 to 103
Standard Deviation	7.91	6.98	6.06	5.50	4.55	3.84	3.29	4.55	3.59	3.75	4.41
					$F_L(100, 120, V, 1.0, H_r)$						
Average Value at 1.0 Mile	120	117	115	112	109	106	103	100	98	96	93
Sample Range	108 to 129	108 to 125	104 to 122	101 to 121	98 to 121	98 to 113	92 to 111	93 to 110	90 to 105	88 to 103	84 to 100
Standard Deviation	7.26	5.22	4.91	6.13	5.69	4.18	5.20	4.95	4.04	4.51	4.63

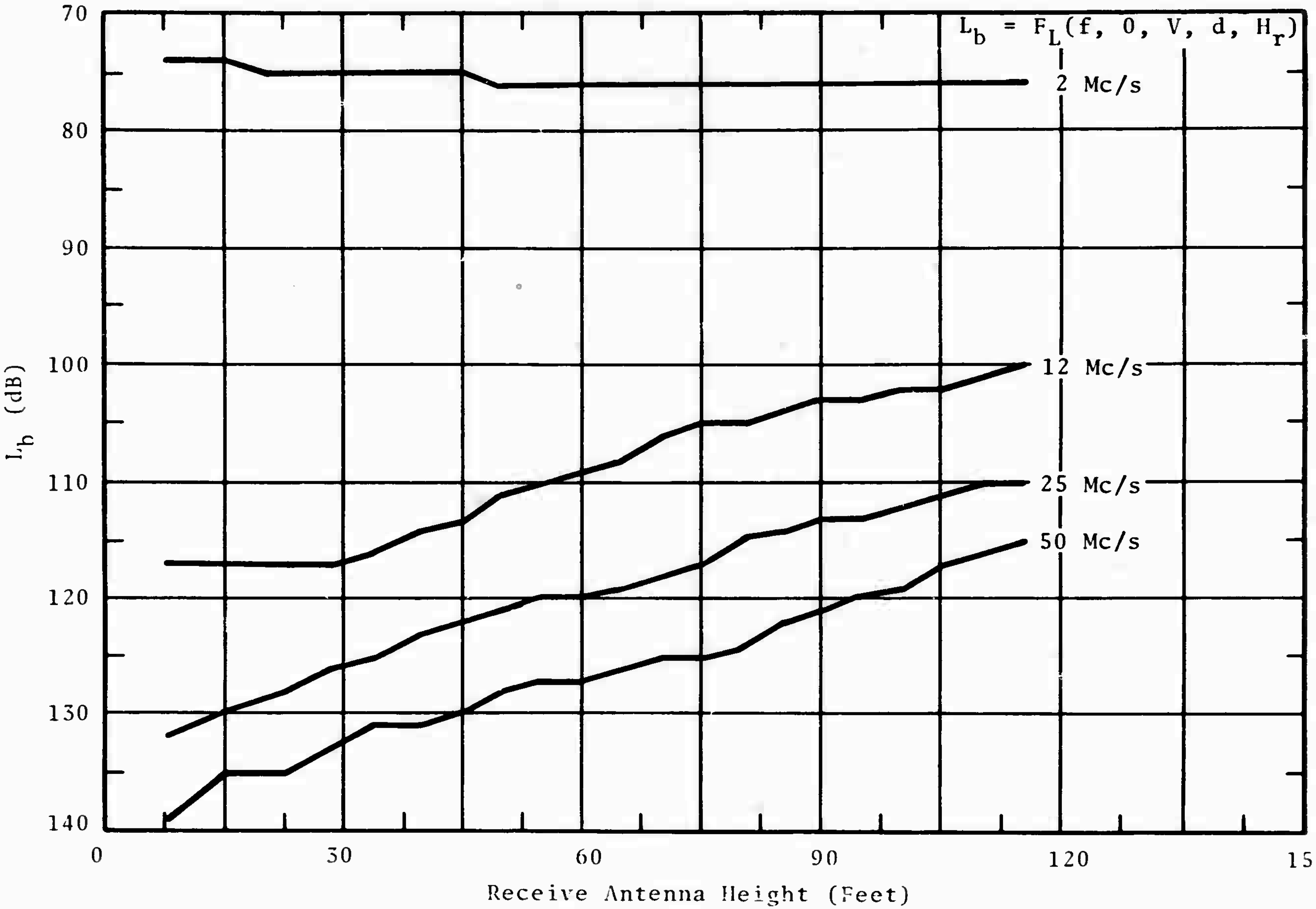

Figure 2.6 Average Height Gain at 1 Mile

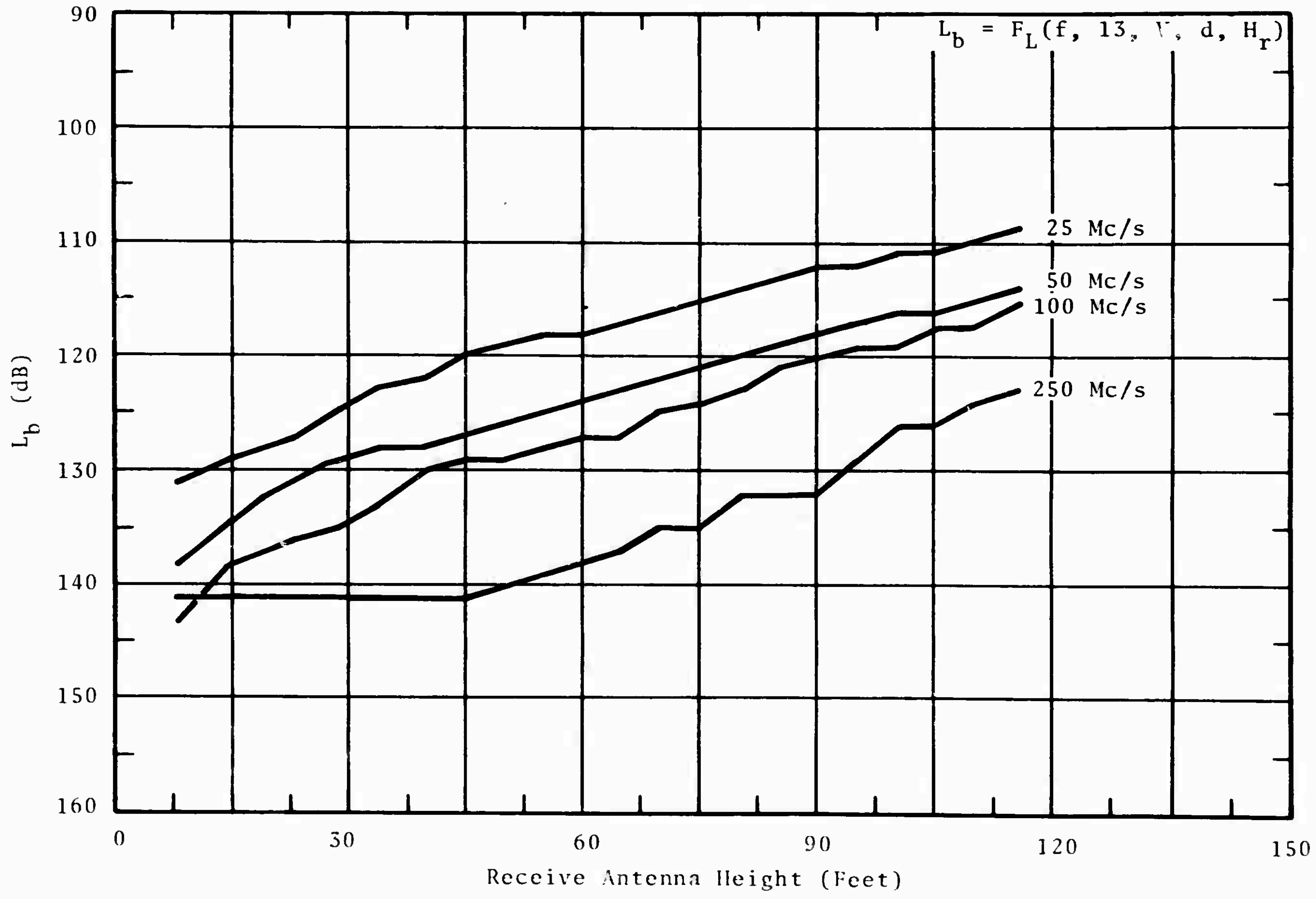

Figure 2.7 Average Height Gain at 1 Mile

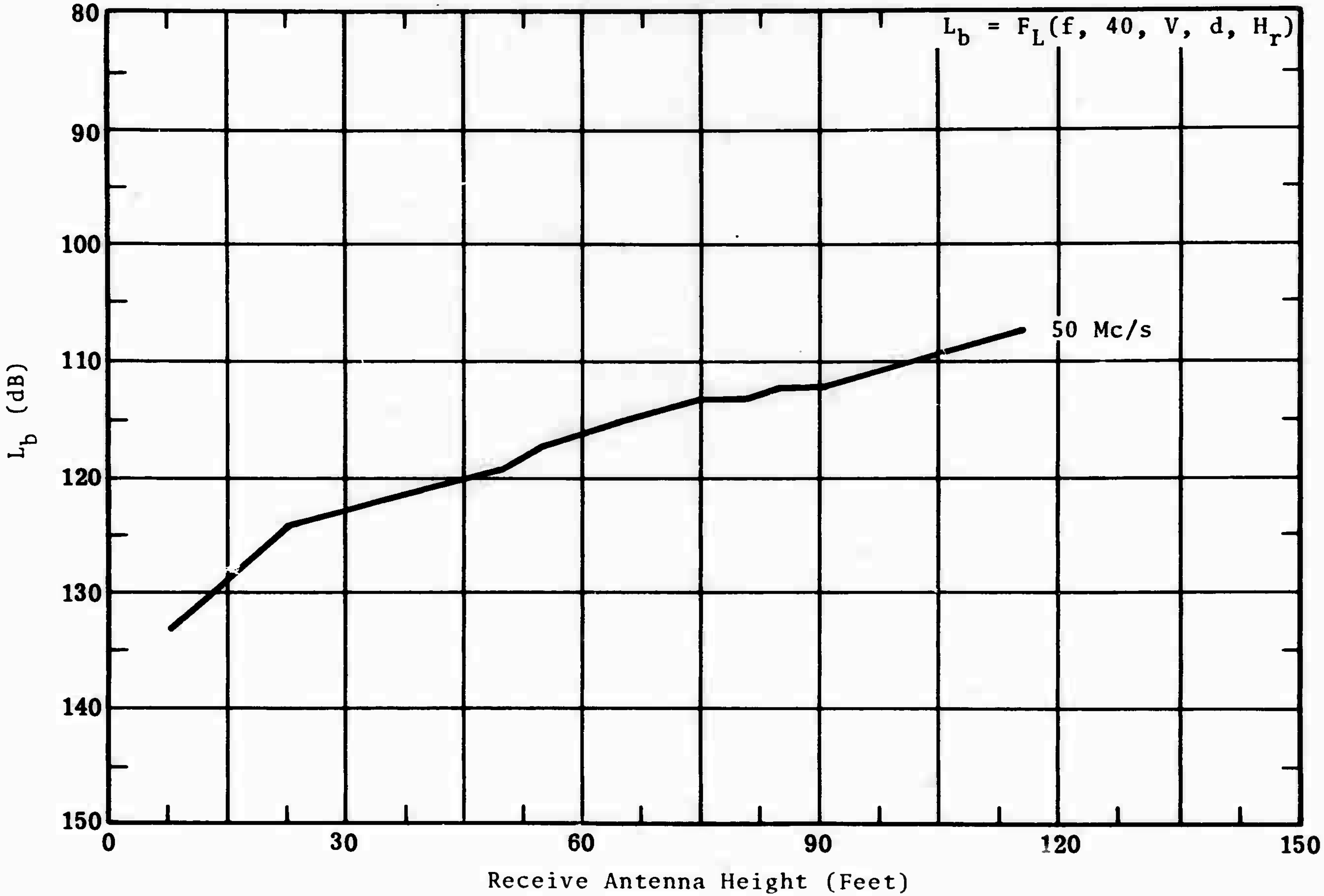

Figure 2.8 Average Height Gain at 1 Mile

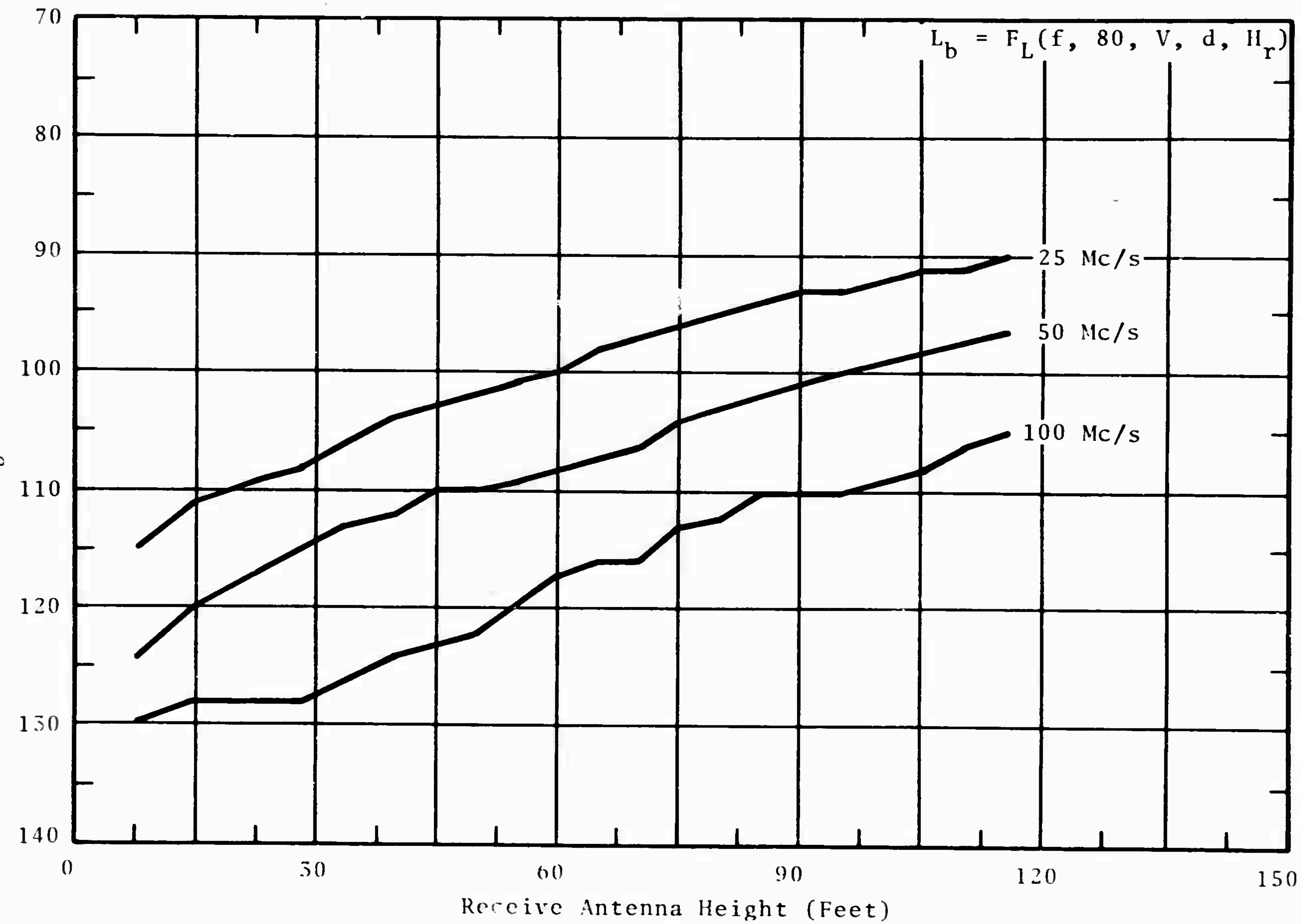

Figure 2.9 Average Height Gain at 1 Mile

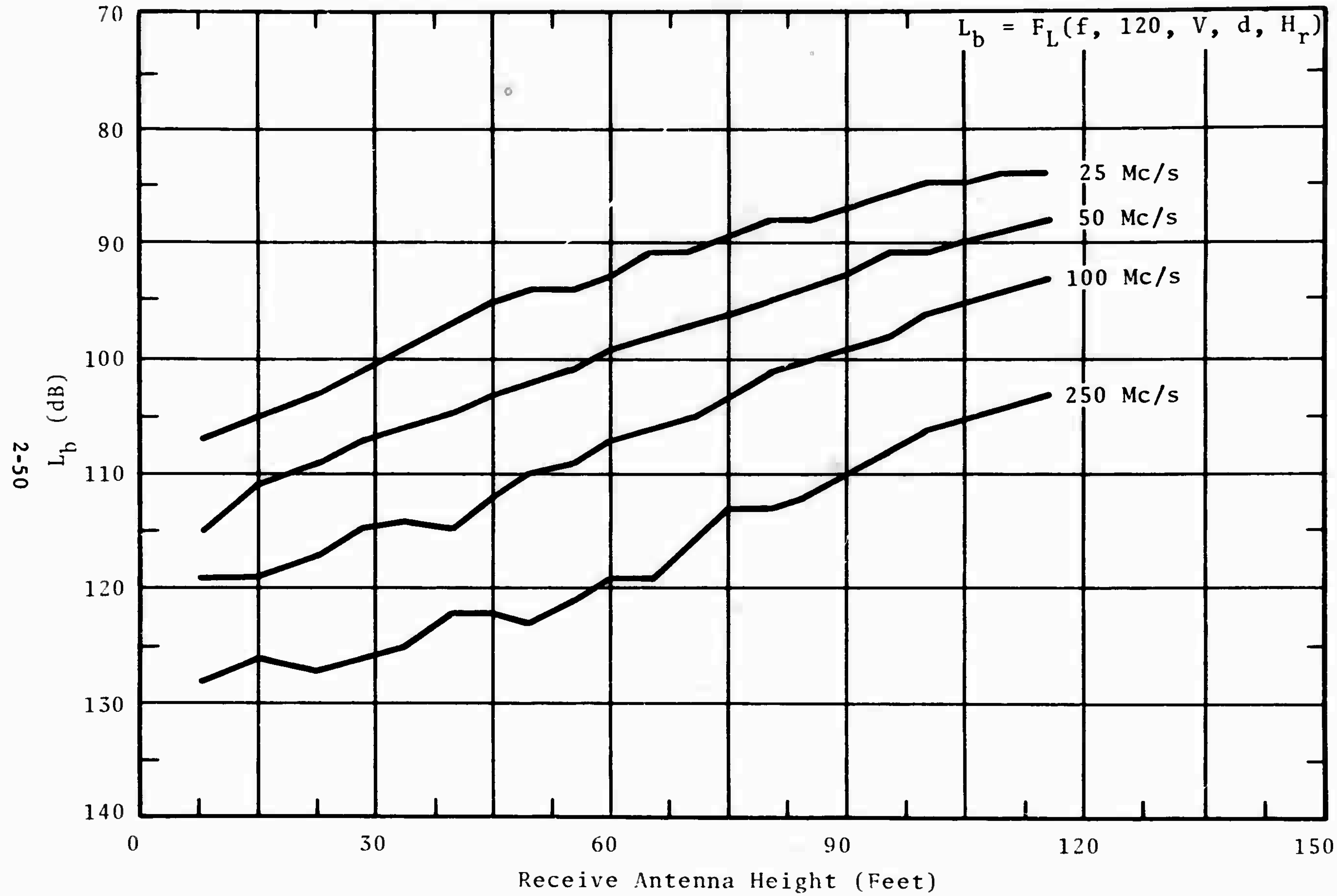

Figure 2.10 Average Height Gain at 1 Mile

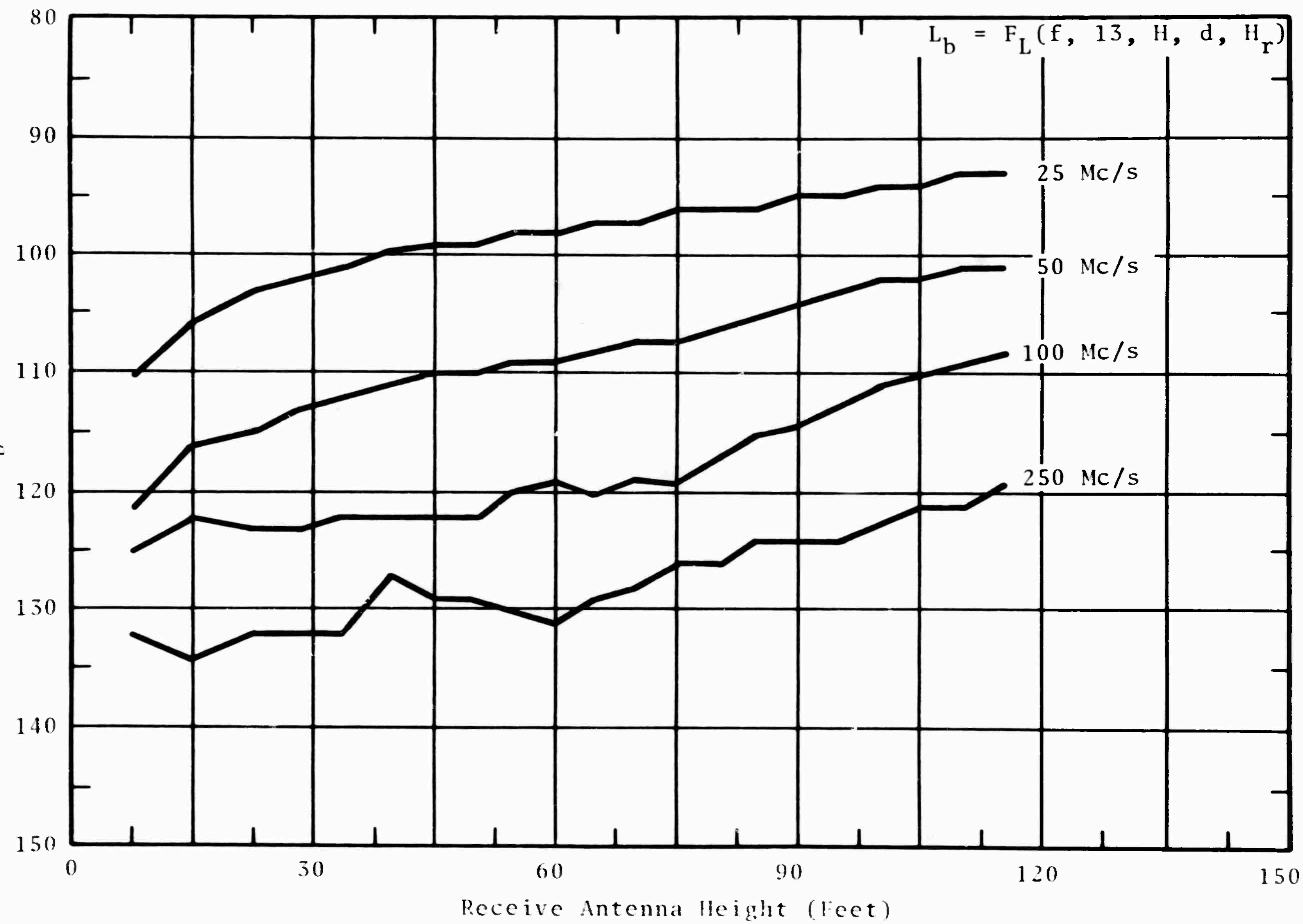

Figure 2.11 Average Height Gain at 1 Mile

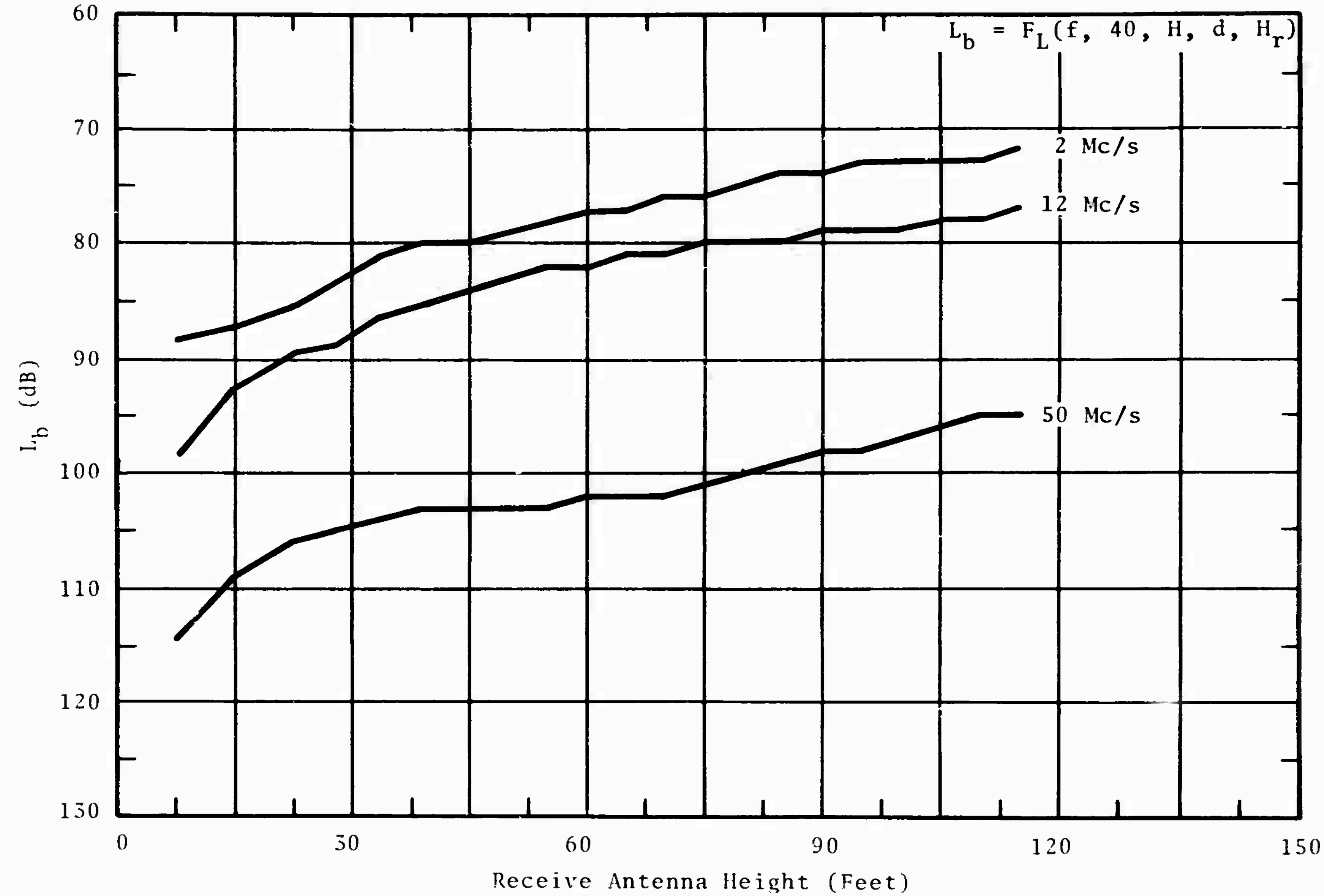

Figure 2.12 Average Height Gain at 1 Mile

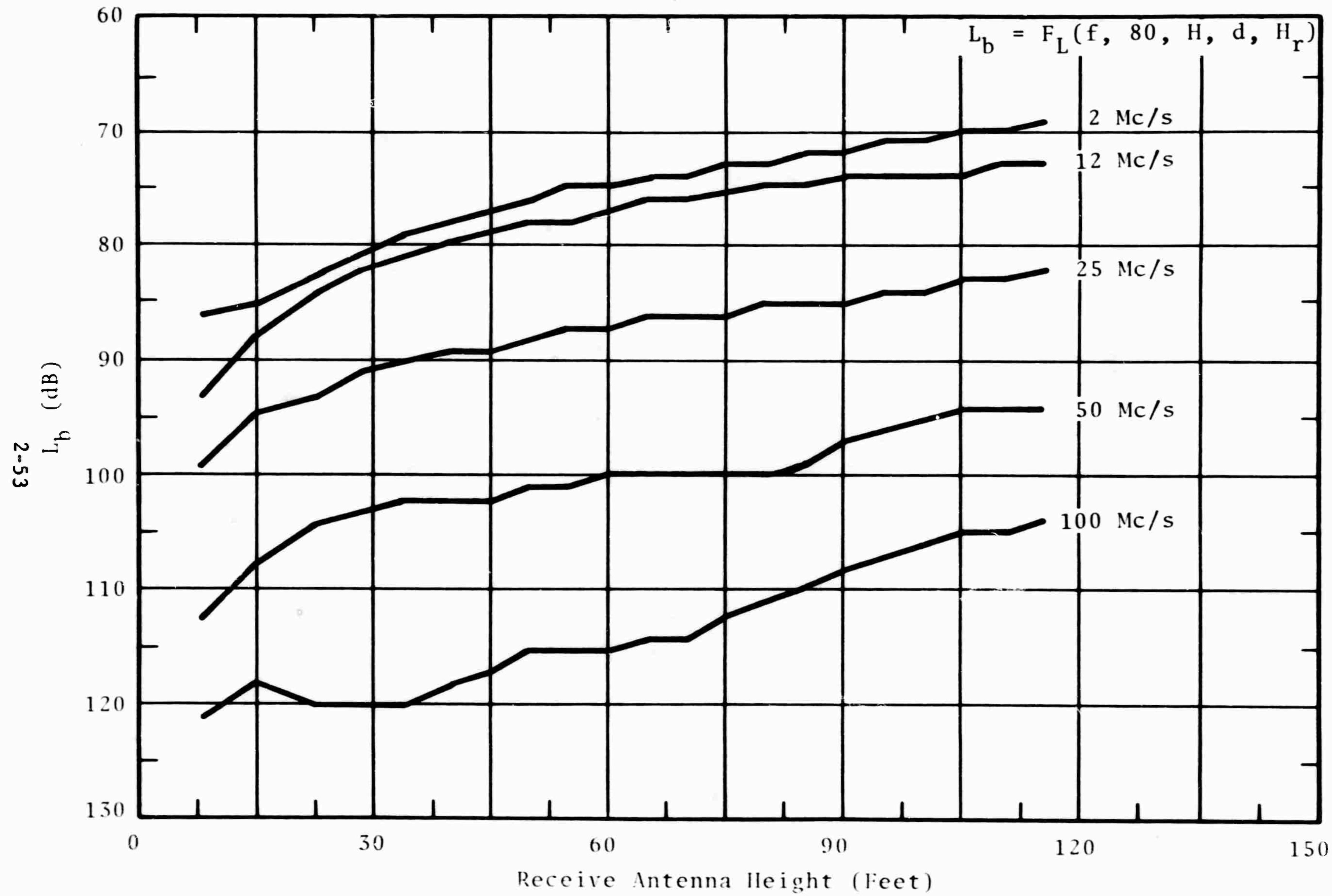

Figure 2.13 Average Height Gain at 1 Mile

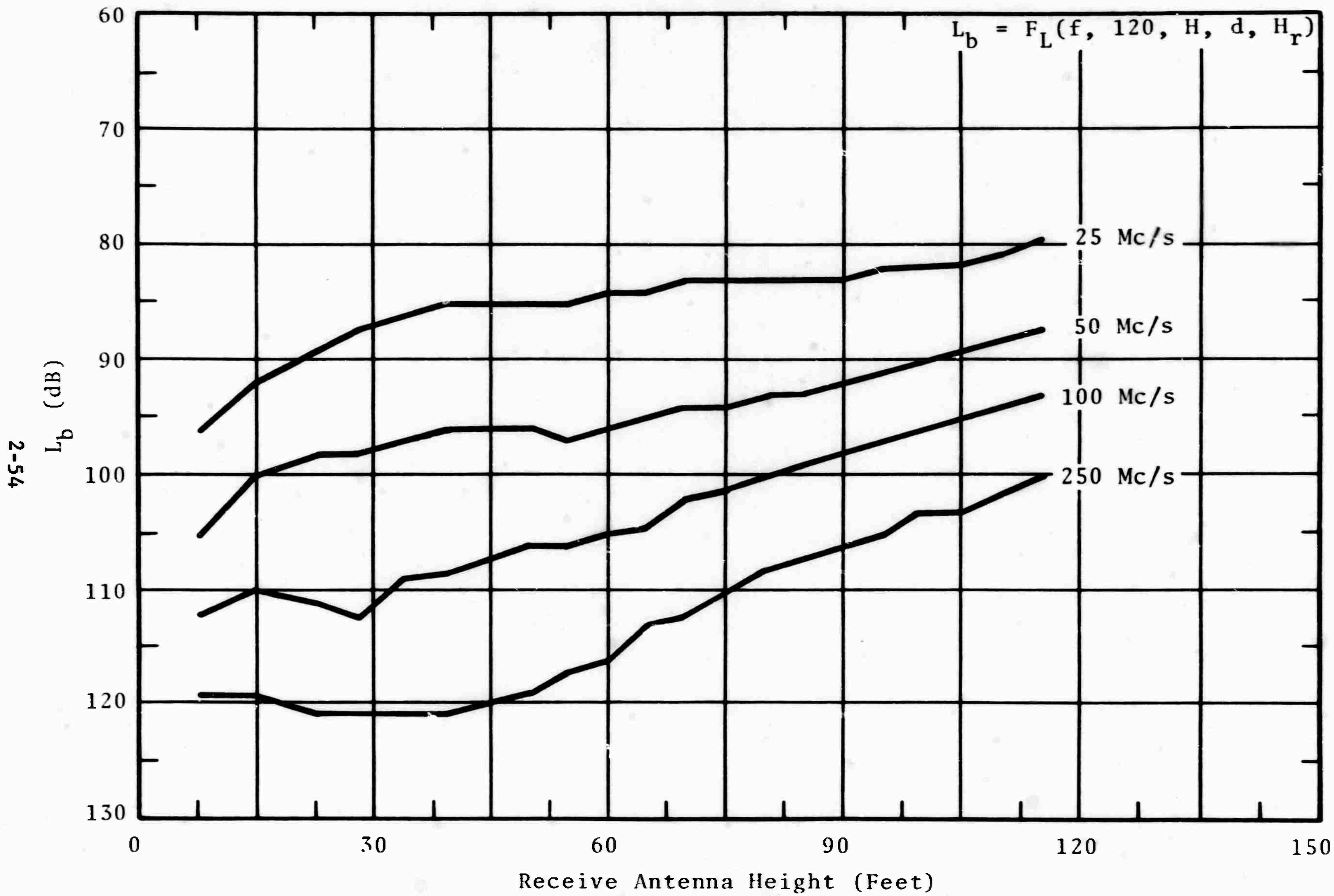

Figure 2.14 Average Height Gain at 1 Mile

between the standard deviations for high and low antennas could be expected if we consider that, in a lateral wave propagation mode, the closer one of the antennas comes to ground, the more foliage appears above it and thus the greater scattering effect the foliage will have on the transmitted signal. Other factors which can contribute to an increasing standard deviation with decreasing receive antenna height are the effects of ground and foliage on transmission parameters and the fact that the measurements made at the low receive antenna heights (8 nd 15 feet) are single point measurements and not the average of a range of measurements.

Making reasonable assumptions about measurement accuracy and data repeatability, it will be realized that the majority of the standard deviations presented are what should be expected, and that even in the low transmit and low receive antenna height configuration the standard deviation is not excessive. Using this type of analysis, it can be said that, in general, the height-gain measurements made at the Area II site do have the 40 log d dependence and when averaged the result is a reasonable estimate of the basic transmission loss for a particular transmit configuration and receive height at 1 mile.

Using the 40 log d dependence, the data was combined to provide average height gain at a normalized distance of 1 mile. The combined data is presented in Figures 2.6 through 2.14 as averaged height gain for each of the transmit antenna configurations of Figure 2.1. Figures 2.6 through 2.10 show the average height gain for each of the test transmit antenna configurations in which vertical polarization was employed. Figures 2.11 through 2.14 present the same information for horizontally polarized test transmissions. Since no height gain was observed at 0.880 Mc/s, an average curve was not plotted for this frequency.

2.4 Comparison of Short Range, Low Receiver Height (Walking) Data with Data from Corresponding Locations in Height-Gain Tests

The walking[4] data, collected between November 1966 and March 1967, was obtained by moving a hand held receiving antenna back and forth (about 10 feet total) about test points along the preselected jungle trails and recording the maximum and minimum field strengths encountered in this interval for various transmitted frequencies, antenna polarizations, and height. Where a definite maximum and minimum could not be obtained, as many as seven measurements were obtained at random locations within this

interval. The receiving antenna was at a height of 6 feet above the local terrain. From these measurements the highest and lowest values of field strength were used to obtain the average path loss. Thus, a fairly large area was sampled to obtain the average path loss for each test point. For the present purposes of comparison with the height-gain measurements of the preceding sections, only those walking data which conformed to the 40 log d dependence, as predicted by the lateral wave mode of propagation, are utilized. This yeilds a total of about 2000 data points for the transmit test configurations which included both polarizations at frequencies of 25, 50, 100 and 250 Mc/s, and transmitter antenna heights of 13, 40, 80 and 120 feet.

The height-gain data, collected between February 1967 and May 1967, which was obtained at the same transmit-receive distances and transmit configurations as the walking data, and at the configuration's lowest reciever height (8 feet), are utilized. The height-gain tests used here thus have a receiver antenna height 2 feet greater than that for the walking tests. This difference is assumed here to have a negligible effect which is justified by the results of the next section. Also, these height-gain measurements are each at a single point in space, as contrasted with the spatial averages for the walking data.

Each of these data sets (walking and height-gain) was broken down into identical subsets for each frequency, transmit antenna height and polarization. Then, all data points of the subsets were normalized to 1 mile and averages taken for each subset. The two sets of average values are given in Table 2.3 along with the differences between the corresponding subset averages.

These differences, which do not exceed 7 dB, appear to be independent of frequency, transmit antenna height, and polarization. The maximum and minimum path loss over the 10-foot probing interval for the walking data (reported in Semiannual Report Number 9) is frequency sensitive and, in general, greater than the 7 dB or less difference between the average path loss of the walking data and the single point results of the height-gain tests (Table 2.37). Thus, the limited seasonal difference in path loss encountered here is within the measurement accuracy, and is considered negligible.

Table 2.37

COMPARISON OF THE AREA II HEIGHT-GAIN AND WALKING
MEASUREMENTS AT 1 MILE AND THE LOWEST RECEIVE ANTENNA HEIGHTS

Freq. (Mc/s)	XMTR Hgt. (ft)	Vertical Pol. L_{bw} dB	Vertical Pol. L_{bhg} dB	Vertical Pol. $L_{bhg}-L_{bw}$ dB	Horizontal Pol. L_{bw} dB	Horizontal Pol. L_{bhg} dB	Horizontal Pol. $L_{bhg}-L_{bw}$ dB
25	13	129	135	+6	114	109	-5
25	40	124	-	-	107	-	-
25	80	120	117	-3	103	99	-4
25	120	110	109	-1	103	96	-7
50	13	148	143	-5	127	122	-5
50	40	141	134	-7	122	117	-5
50	80	133	128	-5	118	115	-3
50	120	124	117	-7	112	107	-5
100	13	148	148	0	133	131	-2
100	40	142	-	-	131	-	-
100	80	137	134	-3	129	126	-3
100	120	126	122	-4	118	114	-4
250	13	149	149	0	145	142	-3
250	40	149	-	-	140	-	-
250	80	139	-	-	138	-	-
250	120	135	130	-5	127	123	-4

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3. SUPPLEMENTARY TESTS

The supplementary tests consisted of a series of measurements to determine transmission losses with hand-carried receiving antennas positioned at different heights and orientations within 10 feet of ground. These measurements were conducted in conjunction with, and as a supplement to, the walking measurements which have been presented in a previous report.[4] Depending on the polarization and type of the receiving antennas, measurements were made at up to 10 different combinations of antenna height and orientation, as shown in Figures 3.1 and 3.2.

3.1 Averaged Supplementary Data

The supplementary data is presented here in tabular form as averages of path losses recorded at points equidistant or nearly equidistant from the transmitting antennas.

The points where the supplementary measurements were made lay on four radial trails and at distances of 200, 1000, 2500, 4900, and 7400 feet from a bench mark at the center of the trails. Since each measurement point has a number representing 1/100 of its distance, in feet, along the trails, the measurement locations can be referred to as points 2, 10, 25, 49, and 74.

Table 3.1 carries the results of a special single set of measurements at 12 Mc/s with horizontal polarization and does not contain average values. Tables 3.2-3.9 show the averaged supplementary data for horizontal and vertical polarization at frequencies of 25, 50, 100, and 250 Mc/s. All data consists of averages taken over at least two, and usually three or four radials.

Each of these tables, which has the results for a particular combination of transmitted frequency and polarization, is broken up into subsets for different transmitting antenna heights. In each antenna height subset are five rows of measured path losses. The different values in each row are for the different receive antenna positions, and the five rows themselves correspond to measurments at points 2, 10, 25, 49, and 74.

The number of the measurement point prefaces each row. Following it is a pair of entries which give the maximum and minimum horizontal transmission distances

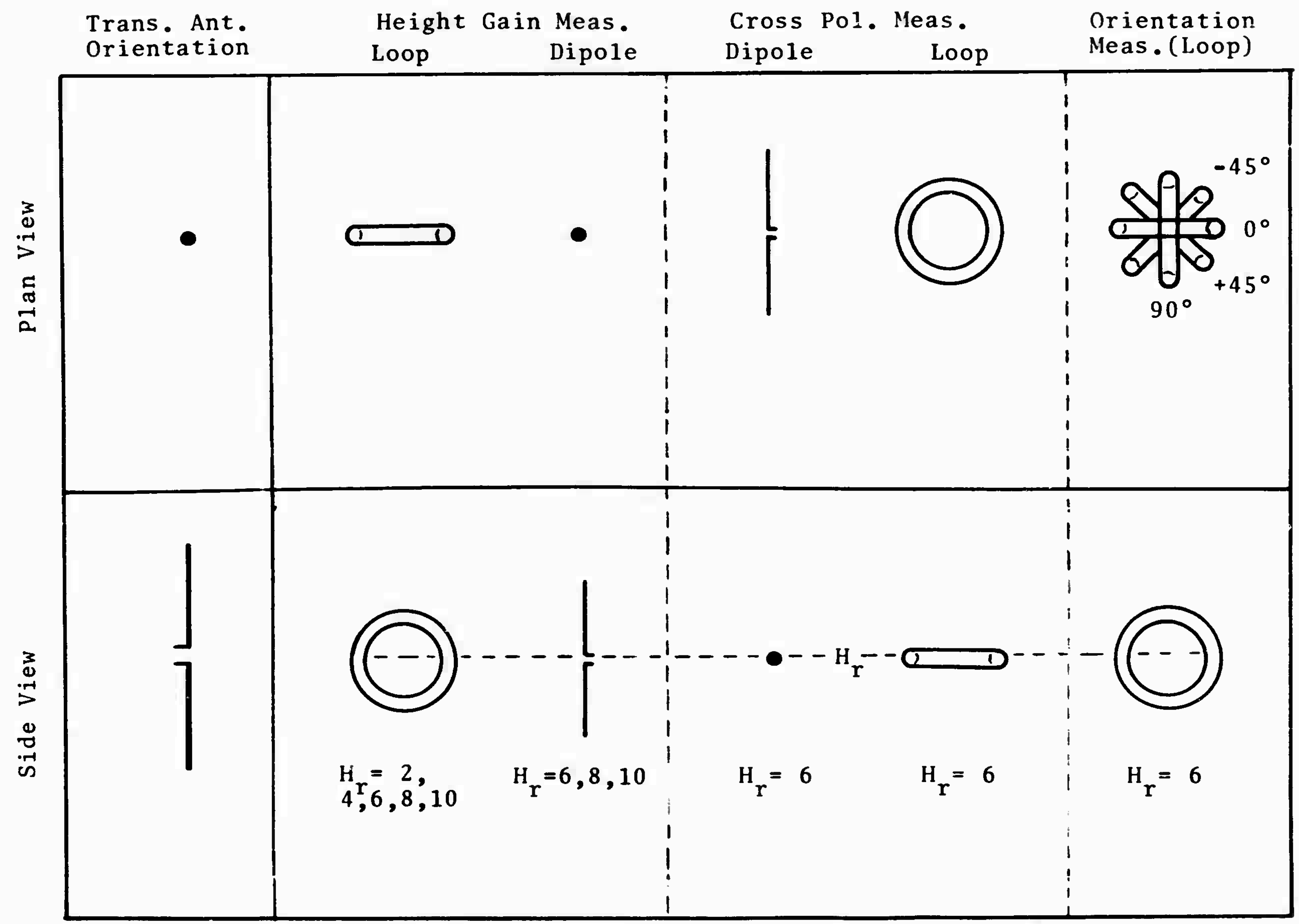

Figure 3.1 Receive Antenna Positions in Supplementary Tests Using Vertically Polarized Transmissions

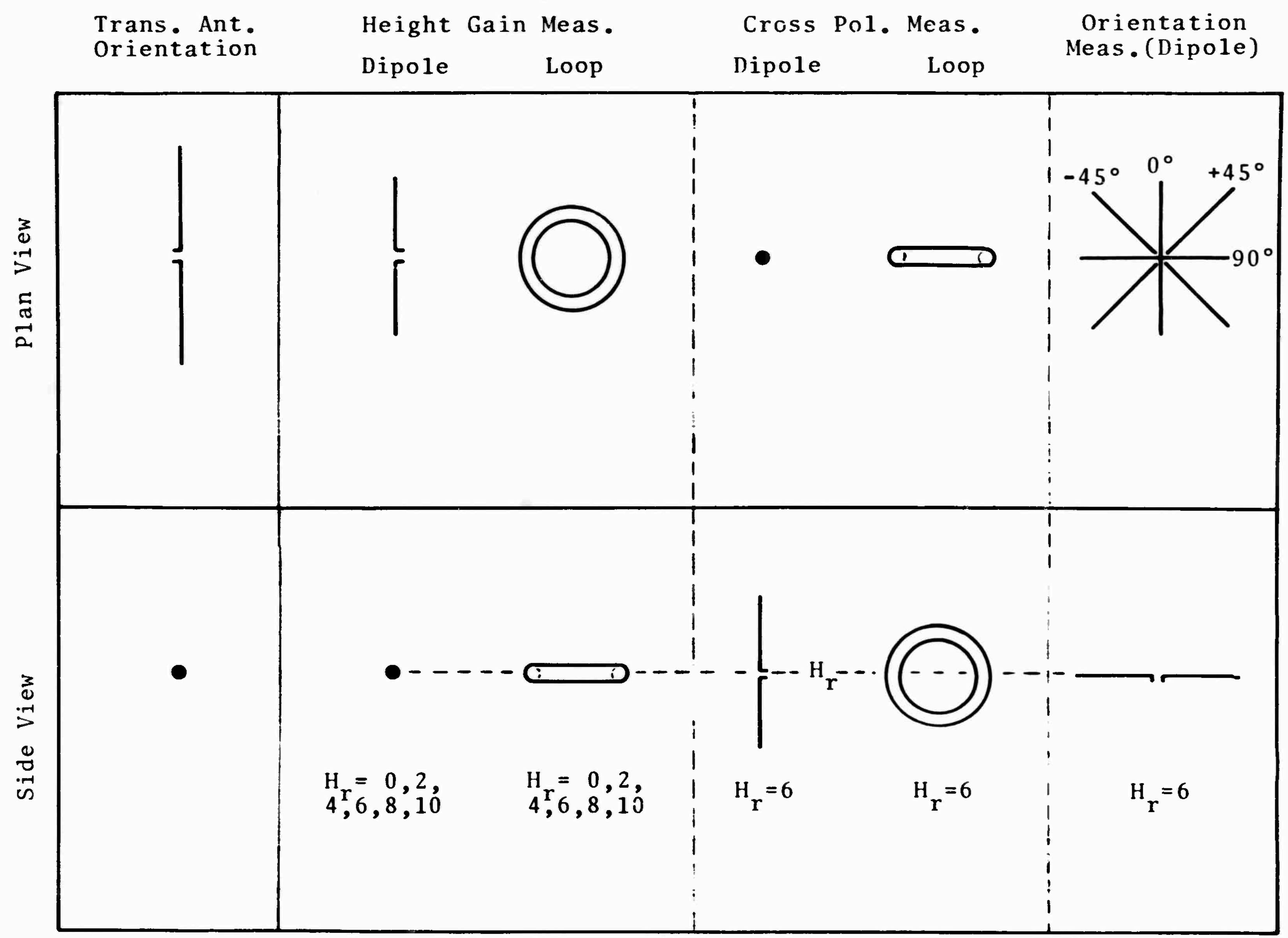

Figure 3.2 Receive Antenna Positions in Supplementary Tests Using Horizontally Polarized Transmissions

involved in that row of averaged data. There is a distance spread because the transmitting antenna locations were offset from the center of the trails, and the spread of distance itself changes when the transmitting locations are changed. Figure 2.2 of Section 2.1 shows the antenna locations and trail orientations.

Except for measurements at point 2 (200 feet from the bench mark) when using the ground plane antenna pad which is offset from the bench mark by 238 feet, the transmission path differences do not significantly affect the data.

As indicated at the top of Tables 3.1-3.9, the first six columns of data are for receive antenna heights of 0, 2, 4, 6, 8, and 10 feet above ground. For these measurements the antenna was in line with the plane of transmitted polarization and oriented toward the transmitting antenna. Columns seven through ten reflect measurements taken at the 6-foot level with different antenna orientations. Column seven is for cross polarized measurements. Columns eight, nine, and ten have data taken with the receive antenna in the same horizontal or vertical plane as the transmitting antenna, but oriented to receive energy arriving at +45 degrees, -45 degrees, and 90 degrees from the direction of the transmitter. The column labels in each table indicate antenna height and polarization or orientation.

Figure 3.1 shows the antenna positions for vertically transmitted polarization. Due to the physical size of the vertical receive antennas, no measurements were made below 6 feet as measured from the antenna center, except with the 25-Mc/s loop which could be lowered to 2 feet above ground. The cross polarization measurement was made with the receive antenna oriented for horizontal polarization. The only orientation measurements for vertical polarization were made by rotating the 25-Mc/s loop to detect vertical components arriving at angles of +45 degrees, -45 degrees, and 90 degrees from the direction of the transmitting antenna.

Figure 3.2 shows the receive antenna positions for horizontally transmitted polarization. All horizontally polarized antennas took readings from ground level to 10 feet. The 6-foot cross polarization measurement was made with the receive antenna oriented for vertical polarization. The three orientation measurements were made with the antennas turned to receive horizontally polarized waves arriving at +45 degrees, -45 degrees, and 90 degrees from the direction of the transmit antenna.

Locations in the tables where no readings were taken or where weak receive signals were not used have "0" in them.

Table 3.1

UNAVERAGED SUPPLEMENTARY DATA

$$L_b = F_Y\ (12,\ H_t,\ H,\ d,\ H_r)$$

LOC PNT	DISTANCE RANGE	0FT H	2FT H	4FT H	6FT H	8FT H	10FT H	6FT V	6FT +45	6FT -45	6FT 90
		RECEIVE ANTENNA POSITION									
TRANSMITTING ANTENNA HEIGHT = 40 FEET											
2	191- 191	60	78	75	74	71	69	89	0	0	0
10	990- 990	112	107	105	103	101	99	104	0	0	0
25	2490-2490	122	117	115	113	112	110	135	0	0	0
49	4890-4890	126	125	122	119	118	115	125	0	0	0
74	7390-7390	143	138	134	132	130	126	142	0	0	0
TRANSMITTING ANTENNA HEIGHT = 80 FEET											
2	191- 191	107	104	102	99	97	96	112	0	0	0
10	990- 990	105	102	100	97	95	94	90	0	0	0
25	2490-2490	117	113	111	110	108	105	124	0	0	0
49	4890-4890	117	114	112	109	107	105	115	0	0	0
74	7390-7390	135	132	117	125	123	123	136	0	0	0

Table 3.2

AVERAGED SUPPLEMENTARY DATA

$$L_b = F_{W,X,Y,Z}\,(25,\ H_t,\ V,\ d,\ H_r)$$

RECEIVE ANTENNA POSITION

REC PNT	DISTANCE RANGE	0FT V	2FT V	4FT V	6FT V	8FT V	10FT V	6FT H	6FT +45	6FT -45	6FT 90
TRANSMITTING ANTENNA HEIGHT = 0 FEET											
2	171- 268	0	61	65	70	72	66	71	61	61	72
10	849- 966	0	100	109	109	111	112	105	106	106	106
25	2338-2449	0	115	119	121	121	122	123	120	122	127
49	4735-4844	0	124	125	126	126	126	128	0	131	130
74	7234-7342	0	0	128	129	130	130	131	132	131	132
TRANSMITTING ANTENNA HEIGHT = 13 FEET											
2	150- 150	0	50	52	56	56	56	73	62	68	72
10	950- 950	0	128	110	111	109	109	112	112	116	112
25	2450-2450	0	0	120	128	126	124	127	125	122	120
49	4850-4850	0	0	125	126	125	124	127	0	0	0
74	7350-7350	0	0	0	133	133	133	133	0	0	0
TRANSMITTING ANTENNA HEIGHT = 40 FEET											
2	184- 218	0	53	54	55	57	60	65	61	66	70
10	984-1018	0	98	97	99	100	101	96	101	96	96
25	2484-2518	0	109	109	109	112	114	108	106	125	110
49	4884-4918	0	119	119	121	120	120	121	0	119	122
74	7384-7418	0	120	124	123	125	127	117	123	127	126
TRANSMITTING ANTENNA HEIGHT = 80 FEET											
2	184- 218	0	56	57	58	58	57	65	60	66	61
10	984-1018	0	90	92	95	93	94	94	94	93	97
25	2484-2518	0	105	103	98	102	103	112	101	106	112
49	4884-4918	0	121	120	118	117	117	122	123	118	115
74	7384-7418	0	117	118	121	121	124	127	122	120	120
TRANSMITTING ANTENNA HEIGHT = 120 FEET											
2	184- 218	0	50	51	51	51	52	59	51	46	50
10	984-1018	0	81	82	83	82	83	92	81	83	86
25	2484-2518	0	95	93	93	94	95	110	92	92	94
49	4884-4918	0	110	108	106	107	107	111	115	107	107
74	7384-7418	0	109	112	113	116	116	121	115	113	115

Table 3.3

AVERAGED SUPPLEMENTARY DATA

$$L_b = F_{W,X,Y,Z}\ (25,\ H_t,\ H,\ d,\ H_r)$$

REC PNT	DISTANCE RANGE	0FT H	2FT H	4FT H	6FT H	8FT H	10FT H	6FT V	6FT +45	6FT -45	6FT 90
		RECEIVE ANTENNA POSITION									
TRANSMITTING ANTENNA HEIGHT = 13 FEET											
2	150- 150	60	54	51	54	51	50	66	0	0	0
10	950- 950	106	99	96	92	89	87	102	0	0	0
25	2450-2450	111	106	102	98	96	94	111	0	0	0
49	4850-4850	125	121	118	112	110	108	124	0	0	0
74	7350-7350	127	124	121	118	115	114	125	0	0	0
TRANSMITTING ANTENNA HEIGHT = 40 FEET											
2	184- 218	57	53	48	47	44	43	67	0	0	0
10	984-1018	90	86	83	83	85	80	90	0	0	0
25	2484-2518	99	97	93	90	88	87	104	0	0	0
49	4864-4918	116	111	107	105	102	101	122	0	0	0
74	7384-7418	121	115	113	112	109	107	127	0	0	0
TRANSMITTING ANTENNA HEIGHT = 80 FEET											
2	184- 218	54	51	48	44	44	40	57	0	0	0
10	984-1018	85	81	77	77	75	73	83	0	0	0
25	2484-2518	100	96	94	88	86	85	96	0	0	0
49	4884-4918	113	111	107	103	101	99	114	0	0	0
74	7384-7418	124	117	113	108	106	105	115	0	0	0
TRANSMITTING ANTENNA HEIGHT = 120 FEET											
2	184- 218	0	0	41	42	40	43	61	0	0	0
10	984-1018	0	0	69	71	69	72	80	0	0	0
25	2484-2518	0	0	86	86	84	89	99	0	0	0
49	4884-4918	0	0	111	102	100	102	108	0	0	0
74	7384-7418	0	0	105	108	105	106	118	0	0	0

Table 3.4

AVERAGED SUPPLEMENTARY DATA

$$L_b = F_{W,X,Y,Z}\ (50,\ H_t,\ V,\ d,\ H_r)$$

REC PNT	DISTANCE RANGE	RECEIVE ANTENNA POSITION 0FT V	2FT V	4FT V	6FT V	8FT V	10FT V	6FT H	6FT +45	6FT -45	6FT 90
TRANSMITTING ANTENNA HEIGHT = 0 FEET											
2	171- 412	0	0	0	83	86	79	80	0	0	0
10.	849-1192	0	0	0	115	117	115	103	0	0	0
25	2338-2687	0	0	0	131	133	126	127	0	0	0
49	4735-5085	0	0	0	143	144	141	129	0	0	0
74	7234-7584	0	0	0	148	146	146	145	0	0	0
TRANSMITTING ANTENNA HEIGHT = 13 FEET											
2	150- 150	0	0	0	71	69	72	72	0	0	0
10	950- 950	0	0	0	115	112	110	108	0	0	0
25	2450-2450	0	0	0	136	134	134	129	0	0	0
49	4850-4850	0	0	0	145	144	143	141	0	0	0
74	7350-7350	0	0	0	150	149	147	147	0	0	0
TRANSMITTING ANTENNA HEIGHT = 40 FEET											
2	184- 218	0	0	0	64	63	62	72	0	0	0
10	984-1018	0	0	0	107	105	102	106	0	0	0
25	2484-2518	0	0	0	130	124	122	127	0	0	0
49	4884-4918	0	0	0	142	141	139	136	0	0	0
74	7384-7418	0	0	0	146	146	146	138	0	0	0
TRANSMITTING ANTENNA HEIGHT = 80 FEET											
2	184- 218	0	0	0	66	65	63	66	0	0	0
10	984-1018	0	0	0	97	99	97	107	0	0	0
25	2484-2518	0	0	0	117	118	117	117	0	0	0
49	4884-4918	0	0	0	132	130	127	125	0	0	0
74	7384-7418	0	0	0	139	140	138	133	0	0	0
TRANSMITTING ANTENNA HEIGHT = 120 FEET											
2	184- 218	0	0	0	69	68	67	70	0	0	0
10	984-1018	0	0	0	92	89	89	93	0	0	0
25	2484-2518	0	0	0	109	106	104	109	0	0	0
49	4884-4918	0	0	0	122	121	121	118	0	0	0
74	7384-7418	0	0	0	128	131	128	124	0	0	0

Table 3.5

AVERAGED SUPPLEMENTARY DATA

$$L_b = F_{W,X,Y,Z}(50, H_t, H, d, H_r)$$

REC PNT	DISTANCE RANGE	RECEIVE ANTENNA POSITION 0FT H	2FT H	4FT H	6FT H	8FT H	10FT H	6FT V	6FT +45	6FT −45	6FT 90
TRANSMITTING ANTENNA HEIGHT = 13 FEET											
2	150- 150	73	58	54	52	50	48	71	57	55	67
10	950- 950	111	98	95	95	94	91	106	95	98	104
25	2450-2450	136	120	117	115	113	111	125	119	118	127
49	4850-4850	142	132	129	126	123	121	145	128	131	141
74	7350-7350	150	141	138	136	134	132	146	139	137	143
TRANSMITTING ANTENNA HEIGHT = 40 FEET											
2	184- 218	74	58	54	52	49	45	79	55	55	71
10	984-1018	112	99	97	97	93	89	98	103	100	99
25	2484-2518	129	113	111	109	106	103	124	113	110	128
49	4884-4918	144	129	125	121	118	116	133	124	125	135
74	7384-7418	145	135	133	134	131	128	133	136	133	142
TRANSMITTING ANTENNA HEIGHT = 80 FEET											
2	184- 218	68	51	48	46	43	41	68	51	51	71
10	984-1018	103	87	85	84	82	80	103	87	89	90
25	2484-2518	130	112	113	112	109	104	123	118	119	124
49	4884-4918	137	122	120	117	114	111	130	123	122	132
74	7384-7418	143	129	126	124	121	118	137	125	125	131
TRANSMITTING ANTENNA HEIGHT = 120 FEET											
2	184- 218	66	49	47	46	43	42	66	51	48	64
10	984-1018	97	82	79	79	77	74	91	82	88	93
25	2484-2518	120	101	99	99	96	94	112	103	102	119
49	4884-4918	130	116	113	108	105	104	125	112	113	127
74	7384-7418	134	124	119	115	114	112	126	119	119	125

Table 3.6

AVERAGED SUPPLEMENTARY DATA

$$L_b = F_{W,X,Y,Z}\ (100,\ H_t,\ V,\ d,\ H_r)$$

REC PNT	DISTANCE RANGE	RECEIVE ANTENNA POSITION 0FT V	2FT V	4FT V	6FT V	8FT V	10FT V	6FT H	6FT +45	6FT -45	6FT 90
TRANSMITTING ANTENNA HEIGHT = 6 FEET											
2	150- 150	0	0	0	69	70	68	70	0	0	0
10	950- 950	0	0	0	117	112	111	113	0	0	0
25	2450-2450	0	0	0	132	131	130	127	0	0	0
49	4850-4850	0	0	0	141	141	141	143	0	0	0
74	7350-7350	0	0	0	147	146	145	144	0	0	0
TRANSMITTING ANTENNA HEIGHT = 13 FEET											
2	150- 150	0	0	0	66	64	62	68	0	0	0
10	950- 950	0	0	0	121	116	109	109	0	0	0
25	2450-2450	0	0	0	139	138	135	132	0	0	0
49	4850-4850	0	0	0	144	143	142	138	0	0	0
74	7350-7350	0	0	0	149	147	145	147	0	0	0
TRANSMITTING ANTENNA HEIGHT = 40 FEET											
2	191- 218	0	0	0	68	67	68	69	0	0	0
10	984-1018	0	0	0	106	107	104	104	0	0	0
25	2484-2518	0	0	0	134	130	126	130	0	0	0
49	4884-4918	0	0	0	140	141	141	137	0	0	0
74	7384-7418	0	0	0	142	141	139	140	0	0	0
TRANSMITTING ANTENNA HEIGHT = 80 FEET											
2	184- 218	0	0	0	63	62	61	59	0	0	0
10	984-1018	0	0	0	107	107	104	104	0	0	0
25	2484-2518	0	0	0	124	129	124	125	0	0	0
49	4884-4918	0	0	0	128	130	126	129	0	0	0
74	7384-7418	0	0	0	139	138	138	136	0	0	0
TRANSMITTING ANTENNA HEIGHT = 120 FEET											
2	184- 218	0	0	0	64	63	61	71	0	0	0
10	984-1018	0	0	0	98	96	97	95	0	0	0
25	2484-2518	0	0	0	114	115	113	110	0	0	0
49	4884-4918	0	0	0	121	120	119	123	0	0	0
74	7384-7418	0	0	0	126	125	123	129	0	0	0

Table 3.7

AVERAGED SUPPLEMENTARY DATA

$$L_b = F_{W,X,Y,Z}\ (100,\ H_t,\ H,\ d,\ H_r)$$

REC PNT	DISTANCE RANGE	RECEIVE ANTENNA POSITION 0FT H	2FT H	4FT H	6FT H	8FT H	10FT H	6FT V	6FT +45	6FT -45	6FT 90
	TRANSMITTING ANTENNA HEIGHT = 6 FEET										
2	150- 150	83	64	58	56	55	54	73	61	58	67
10	950- 950	119	109	110	108	106	102	111	104	115	109
25	2450-2450	134	123	120	118	120	120	130	124	119	127
49	4850-4850	0	149	0	139	137	147	0	141	145	145
74	7350-7350	150	145	141	137	135	135	146	140	139	145
	TRANSMITTING ANTENNA HEIGHT = 13 FEET										
2	150- 150	86	65	58	54	52	50	76	58	59	69
10	950- 950	116	101	100	96	92	90	106	99	97	100
25	2450-2450	140	127	123	119	118	116	134	123	120	126
49	4850-4850	144	138	133	131	131	128	144	134	137	140
74	7350-7350	144	139	137	136	133	133	146	141	140	144
	TRANSMITTING ANTENNA HEIGHT = 40 FEET										
2	184- 218	73	55	50	50	48	47	75	56	52	82
10	984-1018	114	96	91	90	88	85	103	101	100	100
25	2484-2518	138	123	119	121	118	117	130	124	121	133
49	4884-4918	144	136	130	128	129	129	141	132	131	142
74	7384-7418	149	138	134	133	133	133	143	138	137	142
	TRANSMITTING ANTENNA HEIGHT = 80 FEET										
2	184- 218	77	57	53	47	48	48	74	52	54	64
10	984-1018	114	97	90	87	87	89	107	89	93	101
25	2484-2518	136	120	117	112	112	112	129	115	116	127
49	4884-4918	143	127	124	123	122	119	134	126	128	133
74	7384-7418	145	133	132	135	133	132	143	140	135	139
	TRANSMITTING ANTENNA HEIGHT = 120 FEET										
2	184- 218	71	53	49	48	52	56	74	52	52	62
10	984-1018	107	92	88	85	83	81	100	86	90	95
25	2484-2518	119	106	103	103	104	104	123	107	105	114
49	4884-4918	133	123	121	113	113	112	138	114	116	125
74	7384-7418	139	122	121	122	125	121	136	125	125	126

Table 3.8

AVERAGED SUPPLEMENTARY DATA

$$L_b = F_{W,X,Y,Z}\ (250,\ H_t,\ V,\ d,\ H_r)$$

REC PNT	DISTANCE RANGE	RECEIVE ANTENNA POSITION 0FT V	2FT V	4FT V	6FT V	8FT V	10FT V	6FT H	6FT +45	6FT -45	6FT 90
	TRANSMITTING ANTENNA HEIGHT = 13 FEET										
2	150- 150	0	0	0	68	66	65	72	0	0	0
10	950- 950	0	0	0	116	116	114	111	0	0	0
25	2450-2450	0	0	0	136	138	140	135	0	0	0
49	4850-4850	0	0	0	0	0	0	0	0	0	0
74	7350-7350	0	0	0	0	0	0	0	0	0	0
	TRANSMITTING ANTENNA HEIGHT = 40 FEET										
2	195- 218	0	0	0	66	63	62	72	0	0	0
10	994-1018	0	0	0	122	112	111	111	0	0	0
25	2494-2518	0	0	0	139	138	132	138	0	0	0
49	4894-4918	0	0	0	0	0	0	0	0	0	0
74	0- 0	0	0	0	0	0	0	0	0	0	0
	TRANSMITTING ANTENNA HEIGHT = 80 FEET										
2	191- 218	0	0	0	62	64	65	72	0	0	0
10	990-1018	0	0	0	106	111	109	110	0	0	0
25	2490-2518	0	0	0	128	125	124	125	0	0	0
49	4890-4918	0	0	0	134	138	134	143	0	0	0
74	7390-7418	0	0	0	140	140	143	0	0	0	0
	TRANSMITTING ANTENNA HEIGHT = 120 FEET										
2	184- 218	0	0	0	72	70	68	76	0	0	0
10	984-1018	0	0	0	92	91	88	87	0	0	0
25	2484-2518	0	0	0	117	105	96	97	0	0	0
49	4884-4918	0	0	0	124	131	127	137	0	0	0
74	7384-7418	0	0	0	135	130	141	132	0	0	0

Table 3.9

AVERAGED SUPPLEMENTARY DATA

$$L_b = F_{W,X,Y,Z}(250,\ H_t,\ H,\ d,\ H_r)$$

LOC PNT	DISTANCE RANGE	RECEIVE ANTENNA POSITION									
		0FT H	2FT H	4FT H	6FT H	8FT H	10FT H	6FT V	6FT +45	6FT -45	6FT 90
TRANSMITTING ANTENNA HEIGHT = 13 FEET											
2	150- 150	61	60	56	54	52	52	67	58	58	64
10	950- 950	117	105	101	100	102	102	111	104	103	109
25	2450-2450	139	134	139	130	133	131	135	137	136	135
49	4850-4850	0	133	0	134	142	136	0	139	141	0
74	7350-7350	0	0	141	139	135	141	0	0	142	0
TRANSMITTING ANTENNA HEIGHT = 40 FEET											
2	194- 218	72	57	57	55	60	55	73	64	56	67
10	994-1018	112	103	104	103	97	96	107	101	104	103
25	2494-2518	143	129	129	131	126	133	130	130	128	133
49	4894-4918	0	138	137	137	140	141	0	0	141	143
74	7394-7418	0	131	138	141	133	135	143	141	142	142
TRANSMITTING ANTENNA HEIGHT = 80 FEET											
2	191- 218	75	58	57	62	54	59	77	66	63	71
10	990-1018	122	108	107	102	99	92	111	107	105	108
25	2490-2518	137	121	128	123	125	125	132	126	125	131
49	4890-4918	139	137	136	131	134	141	139	135	135	139
74	7390-7418	0	137	136	136	129	135	0	0	141	137
TRANSMITTING ANTENNA HEIGHT = 120 FEET											
2	184- 218	67	56	70	62	59	59	75	62	69	70
10	984-1018	101	89	85	86	87	88	100	89	88	96
25	2484-2518	125	109	112	111	111	114	120	116	117	118
49	4884-4918	135	127	124	123	122	128	133	124	125	128
74	7384-7418	137	129	128	129	129	125	133	131	130	129

3.2 Median Effect of Changing the Receive Antenna Position

The supplementary data has been further analyzed to obtain median values for changes in path loss which result when the height or orientation of the receive antenna is changed relative to some standard position.

The standard receive position has been chosen as that in which the antenna is 6 feet above ground, oriented toward the transmitting antenna, and in line with the plane of transmitted polarization. (This is the position in the fourth data column of Tables 3.1-3.9.) This position combination was chosen because a great deal of data exists for it, including the walking measurements and tower measurements. Also, the cross polarization and orientation tests were conducted at the 6-foot level.

The averaged supplementary data was grouped into 90 sets corresponding to the 10 receive antenna positions multiplied by the 9 combinations of frequency and polarization. The 9 combinations of frequency and polarization result from horizontal polarization at 12 Mc/s and vertical and horizontal polarization at 25, 50, 100, and 250 Mc/s. Obviously, there was no data for some sets, since all the receive antennas could not be put into all positions.

Within each set the differences between the measured path losses (for all combinations of path, transmitting antenna height, and distance) and the path losses for the appropriate standard position were determined. Tables 3.10 through 3.14 list the median value of these differences, the standard deviation, and the number of samples for each set.

Table 3.10

MEDIAN PATH LOSS CHANGES WITH RESPECT TO
STANDARD RECEIVE ANTENNA POSITION

$F_y\ (12,\ H_t,\ H,\ d,\ H_r)$

	RECEIVE ANTENNA POSITION									
	0FT H	2FT H	4FT H	6FT* H	8FT H	10FT H	6FT V	6FT +45	6FT -45	6FT 90
Median Change in Path Loss (dB)	8.0	5.0	2.0	0.0	-2.0	-4.0	10.0	0.0	0.0	0.0
Standard Deviation (dB)	2.0	1.1	3.1	0.0	0.5	0.9	5.8	0.0	0.0	0.0
Number of Samples	11	11	11	11	11	11	11	0	0	0

*Standard position

Table 3.11

MEDIAN PATH LOSS CHANGES WITH RESPECT TO STANDARD RECEIVE ANTENNA POSITION

$F_{W,X,Y,Z}\ (25,\ H_t,\ V,\ d,\ H_r)$

	RECEIVE ANTENNA POSITION									
	0FT V	2FT V	4FT V	6FT* V	8FT V	10FT V	6FT H	6FT +45	6FT -45	6FT 90
Median Change in Path Loss (dB)	0.0	-2.0	-1.0	0.0	0.0	1.0	3.0	1.0	1.0	2.0
Standard Deviation (dB)	0.0	5.0	3.4	0.0	2.4	4.0	8.1	4.8	6.3	6.8
Number of Samples	0	50	63	67	67	67	60	31	33	33

$F_{W,X,Y,Z}\ (25,\ H_t,\ H,\ d,\ H_r)$

	RECEIVE ANTENNA POSITION									
	0FT H	2FT H	4FT H	6FT* H	8FT H	10FT H	6FT V	6FT +45	6FT -45	6FT 90
Median Change in Path Loss (dB)	10.0	5.0	2.0	0.0	-2.0	-4.0	10.0	0.0	0.0	0.0
Standard Deviation (dB)	1.7	1.4	1.3	0.0	1.8	4.1	6.6	0.0	0.0	0.0
Number of Samples	24	25	30	70	70	70	65	0	0	0

*Standard position

Table 3.12

MEDIAN PATH LOSS CHANGES WITH RESPECT TO
STANDARD RECEIVE ANTENNA POSITION

$F_{W,X,Y,Z}\ (50,\ H_t,\ V,\ d,\ H_r)$

	RECEIVE ANTENNA POSITION									
	0FT V	2FT V	4FT V	6FT* V	8FT V	10FT V	6FT H	6FT +45	6FT -45	6FT 90
Median Change in Path Loss (dB)	0.0	0.0	0.0	0.0	-1.0	-2.0	-3.5	0.0	0.0	0.0
Standard Deviation (dB)	0.0	0.0	0.0	0.0	4.2	4.3	8.5	0.0	0.0	0.0
Number of Samples	0	0	0	84	84	84	84	0	0	0

$F_{W,X,Y,Z}\ (50,\ H_t,\ H,\ d,\ H_r)$

	RECEIVE ANTENNA POSITION									
	0FT H	2FT H	4FT H	6FT* H	8FT H	10FT H	6FT V	6FT +45	6FT -45	6FT 90
Median Change in Path Loss (dB)	19.0	4.0	2.0	0.0	-3.0	-5.0	14.0	3.0	3.0	13.0
Standard Deviation (dB)	4.0	3.7	2.6	0.0	2.2	3.1	9.3	4.4	4.7	9.3
Number of Samples	63	70	70	70	70	70	69	70	70	69

*Standard position

Table 3.13

MEDIAN PATH LOSS CHANGES WITH RESPECT TO
STANDARD RECEIVE ANTENNA POSITION

$F_{W,X,Y,Z}$ (100, H_t, V, d, H_r)

	RECEIVE ANTENNA POSITION									
	0FT V	2FT V	4FT V	6FT* V	8FT V	10FT V	6FT H	6FT +45	6FT -45	6FT 90
Median Change in Path Loss (dB)	0.0	0.0	0.0	0.0	-1.0	-3.0	-2.0	0.0	0.0	0.0
Standard Deviation (dB)	0.0	0.0	0.0	0.0	3.4	4.7	6.4	0.0	0.0	0.0
Number of Samples	0	0	0	77	77	77	77	0	0	0

$F_{W,X,Y,Z}$ (100, H_t, H, d, H_r)

	RECEIVE ANTENNA POSITION									
	0FT H	2FT H	4FT H	6FT* H	8FT H	10FT H	6FT V	6FT +45	6FT -45	6FT 90
Median Change in Path Loss (dB)	20.0	6.0	2.0	0.0	-1.0	-2.0	14.7	4.0	4.0	11.0
Standard Deviation (dB)	7.9	5.9	4.7	0.0	3.2	5.1	8.5	4.4	5.1	9.1
Number of Samples	71	78	77	78	78	78	71	78	78	73

*Standard position

Table 3.14

MEDIAN PATH LOSS CHANGES WITH RESPECT TO
STANDARD RECEIVE ANTENNA POSITION

$F_{W,X,Y,Z}$ (250, H_t, V, d, H_r)

	RECEIVE ANTENNA POSITION									
	0FT V	2FT V	4FT V	6FT* V	8FT V	10FT V	6FT H	6FT +45	6FT -45	6FT 90
Median Change in Path Loss (dB)	0.0	0.0	0.0	0.0	0.0	-0.5	1.0	0.0	0.0	0.0
Standard Deviation (dB)	0.0	0.0	0.0	0.0	9.0	9.4	10.5	0.0	0.0	0.0
Number of Samples	0	0	0	33	33	32	32	0	0	0

$F_{W,X,Y,Z}$ (250, H_t, H, d, H_r)

	RECEIVE ANTENNA POSITION									
	0FT H	2FT H	4FT H	6FT* H	8FT H	10FT H	6FT V	6FT +45	6FT -45	6FT 90
Median Change in Path Loss (dB)	14.0	1.0	1.4	0.0	-1.0	-1.0	10.0	4.0	2.5	5.0
Standard Deviation (dB)	7.2	5.5	4.8	0.0	5.3	5.9	7.8	4.2	4.3	7.0
Number of Samples	29	40	41	42	42	41	36	39	42	38

*Standard position

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4. SHORT RANGE 10-GC/S TESTS

The measurement program at the Area II test site for frequencies from 550 Mc/s to 10 Gc/s has now been completed. Two test series were performed in this frequency range: short range attenuation tests and treetop mode tests.

The short range attenuation tests have been conducted in the manner which is described in the Final Report Volume 1.[5] The tests were made over two paths called Range 1 and Range 2. Range 1 had a transmission distance of 312 feet and a foliage depth of 252 feet. Range 2 had 303 and 243 feet, respectively. At each range, combinations of five transmit and receive heights (9, 33, 57, 81, and 99 feet above ground level), two polarizations (vertical and horizontal), and five frequencies (0.550, 1.00, 2.50, 5.00, and 10.00 Gc/s) were tested.

The treetop mode tests have also been described in Final Report Volume 1[6] and essentially the same techniques were used at the Area II test site. The results of these tests will be presented in a future report.

During the tests, foliage maps and descriptions were prepared. They are presented in this section. It is realized that these descriptions are only qualitative, since relationships between vegetative and electrical parameters are lacking. Thus, the information presented is an attempt to give as much insight as possible from observations by experienced field personnel.

4.1 Description of Foliage in the Area II Site

Although foliage descriptions of the Area II test site have been presented in a previous seniannual report,[7] they were prepared for the general test site area, and the descriptors are more applicable for analysis of the lower frequency data.

In contrast, foliage descriptions of the two ranges used in Area II have been prepared by field personnel to completely describe the small but specific area in which attenuation tests have been made. The descriptions have been prepared to aid in the analysis of the 0.550- to 10-Gc/s program measurements. The foliage descriptions consist of a foliage map and a foliage description, both prepared by the field personnel.

4.1.1 Line-of-Sight Foliage Maps

In order to estimate the locations of each tree or obstacle in the vicinity of the line-of-sight path, a tape measure was positioned (as close to a straight line as possible) between the centers of the transmitter and receiver towers. Each tree greater than 1 inch in diameter was recorded by noting its range with respect to the tape measure and its distance from the tape. Tree diameters were measured and rough estimates were made of tree heights for all trees within 20 feet of the tape and large trees within 30 feet. The biggest trees were accurately measured by climbing one of the antenna towers and sighting horizontally. The resulting foliage maps are shown for Ranges 1 and 2 in Figures 4.1 and 4.2, respectively. The nomenclature beside each tree indicates the tree diameter at breast level in inches and the tree height in feet.

4.1.2 Foliage Descriptions as Seen from Receiving Towers

The foliage which most affects the measurement of attenuation between two antennas immersed in the foliage is that which is nearest the antenna apertures. Since the transmitting antennas are used in a clearing, even the nearest foliage is 60 feet away when measured on the line of sight. Thus, little effect due to specific leaves or branches can be expected. However, in the case of the receiving antenna, the foliage can be fairly close to the antenna. For this reason, foliage descriptions have been prepared and photographs taken only of the foliage near the receiver tower. These descriptions are, of course, only qualitative; however, they have been prepared by experienced field personnel so that as much insight as possible between the foliage and the electrical parameters can be provided. Because the view from the receiver towers depends on the height above ground, there is a description for each antenna height. Photographs accompany the descriptions for Range 1; no photographs were taken over Range 2.

Views from Range 1 Receiver Tower (see Figures 4.3 - 4.7)

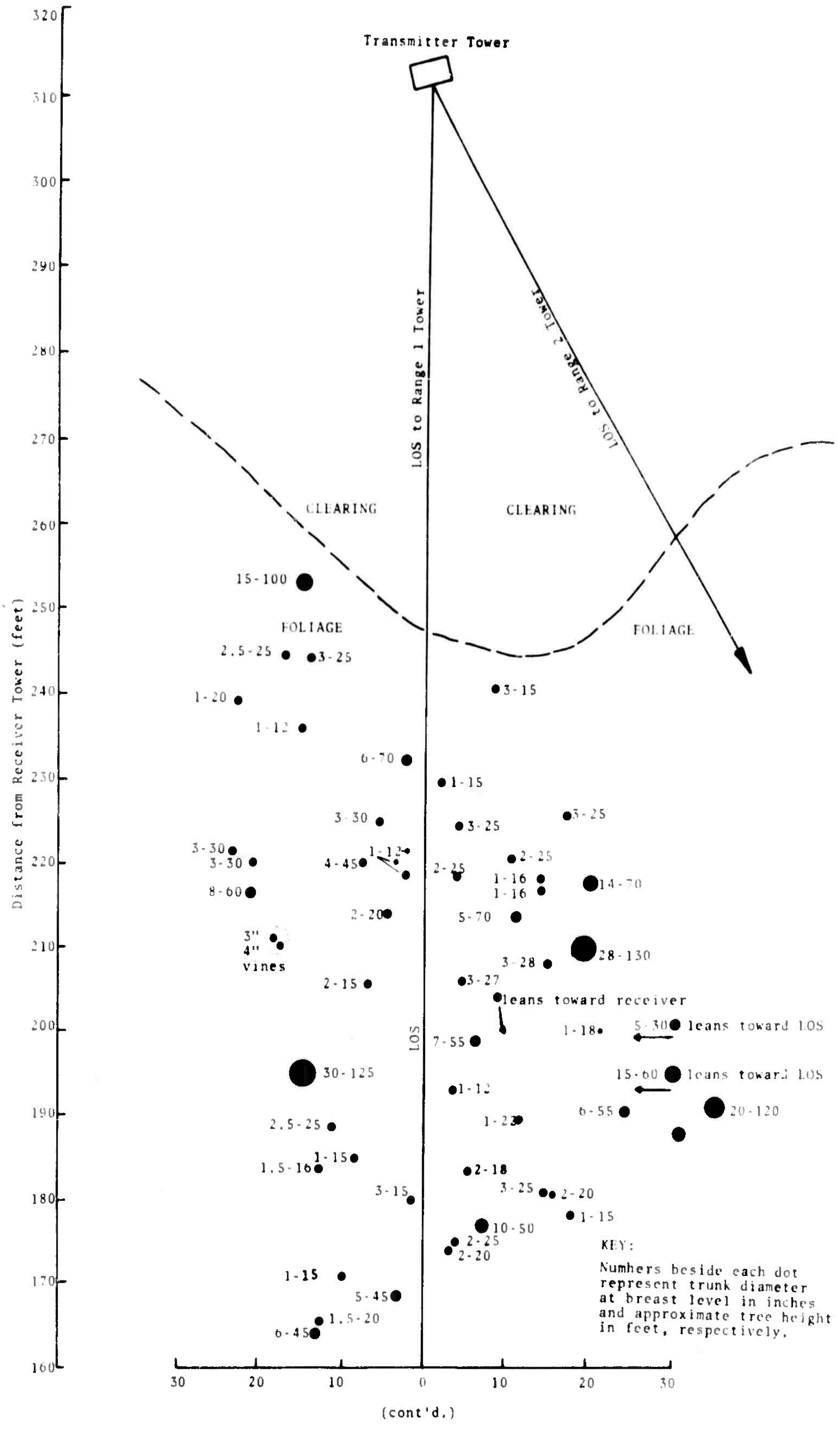


Figure 4.1a Range 1 Foliage Map

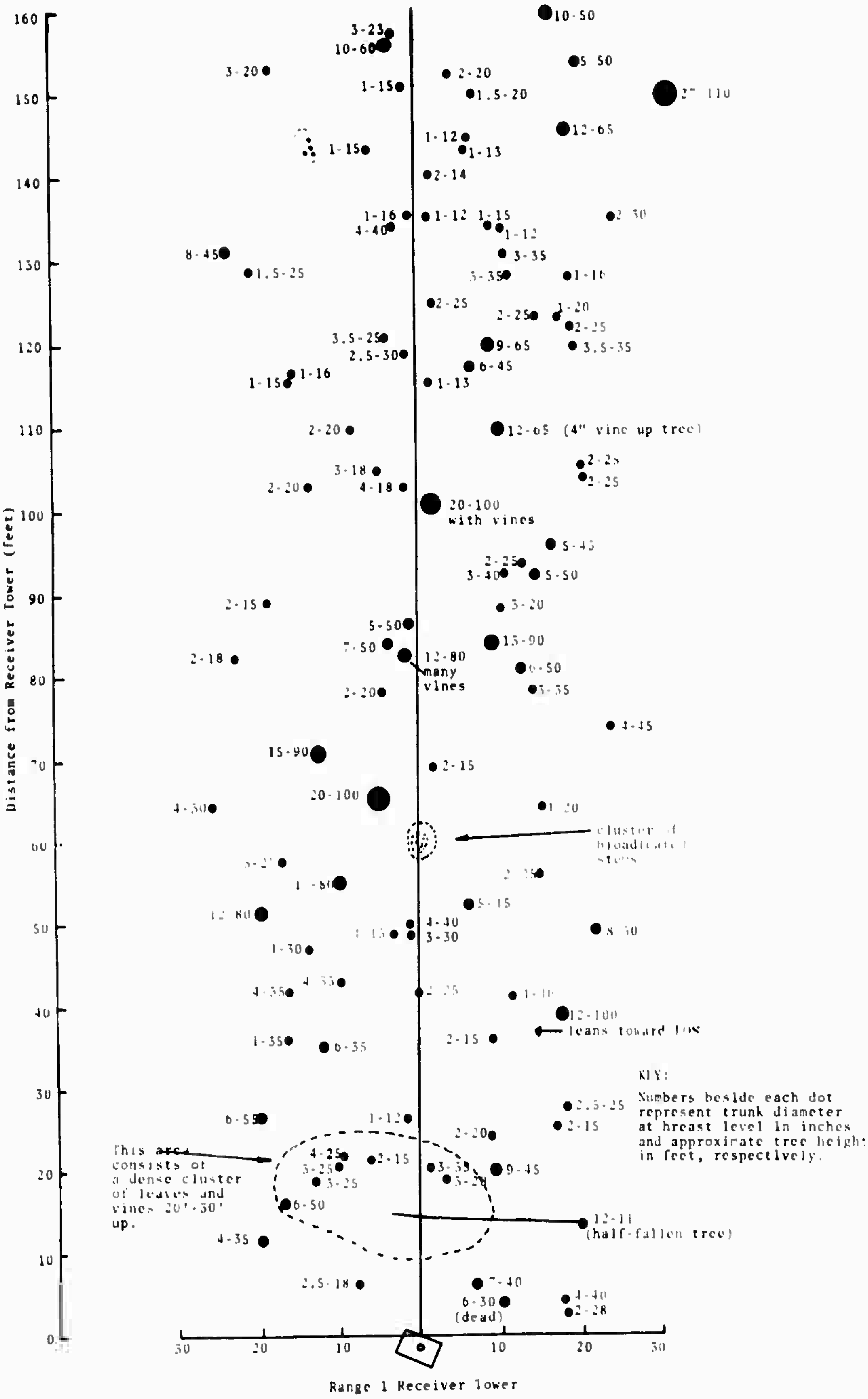
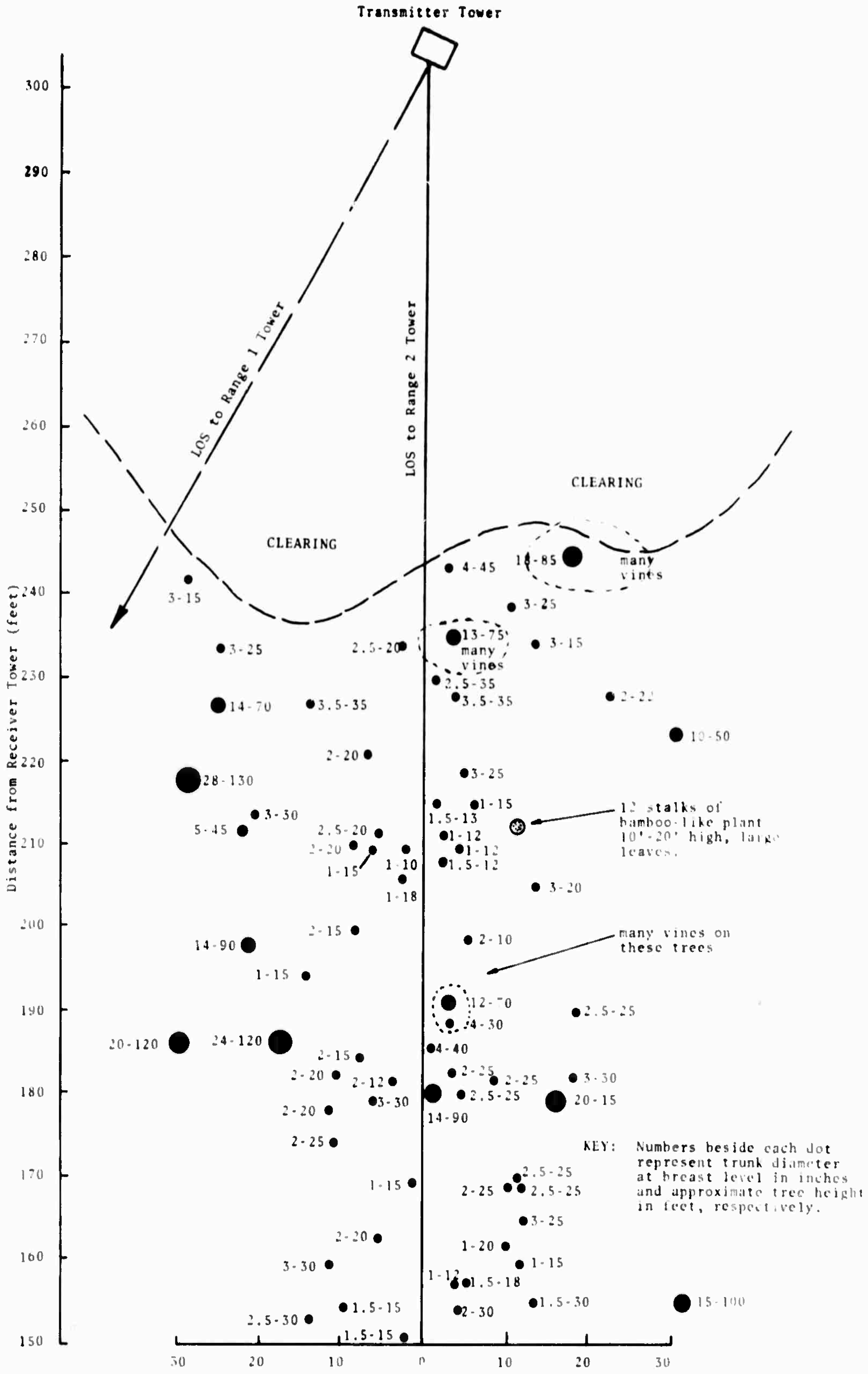


Figure 4.1b Range 1 Foliage Map



(cont'd.)

Figure 4.2a Range 2 Foliage Map

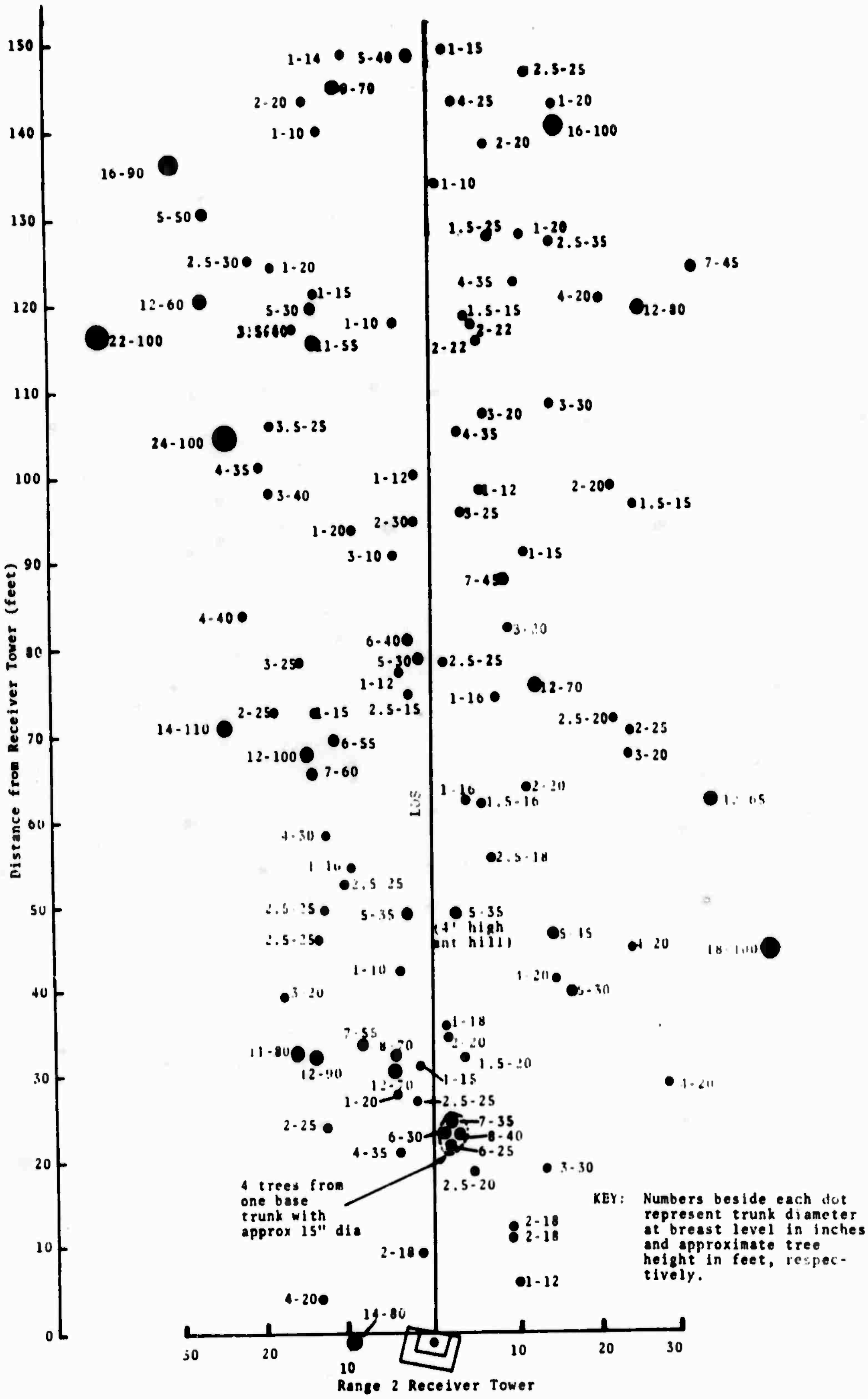


Figure 4.2b Range 2 Foliage Map

Figure 4.3 View from Range 1 Receiver Tower at 9-Foot Height

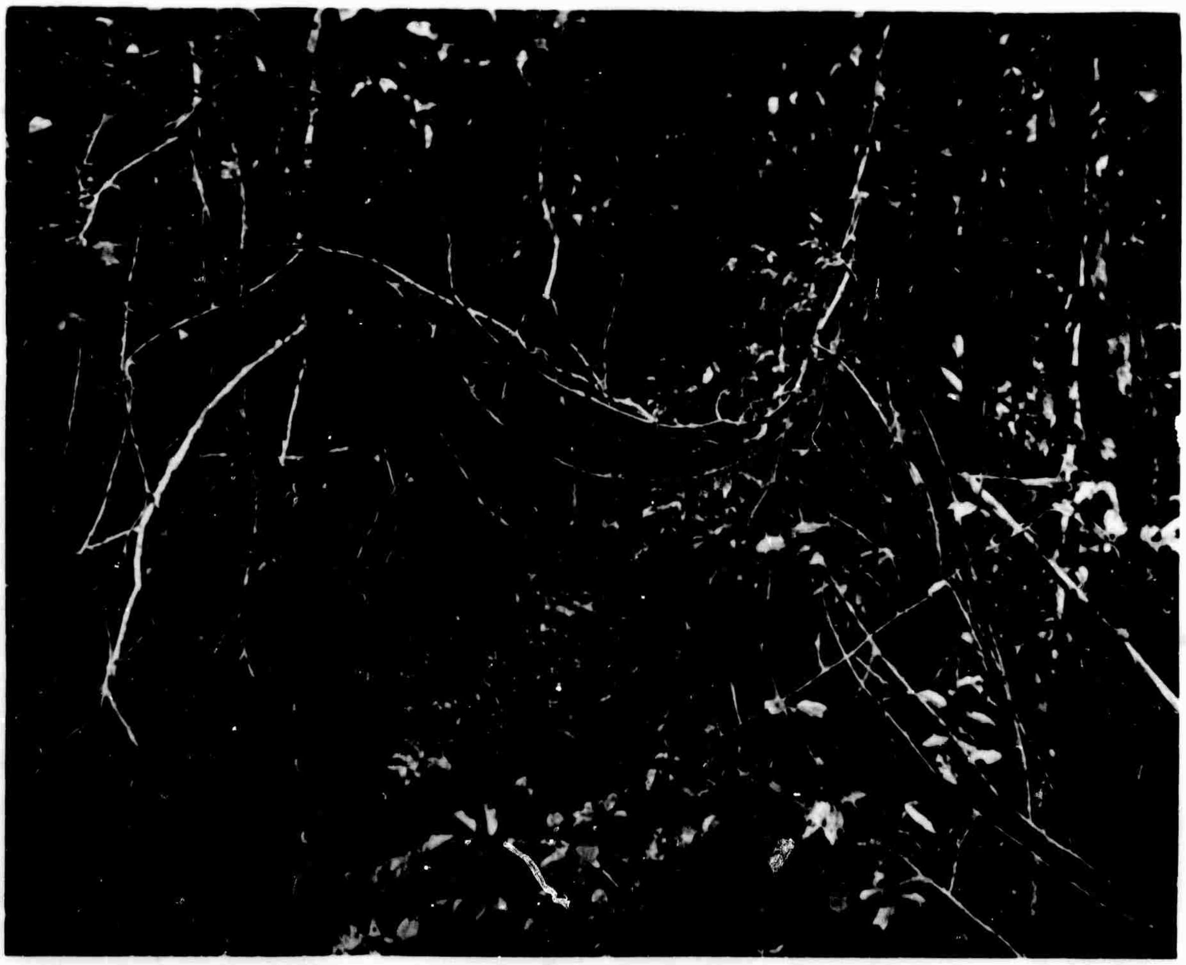


Figure 4.4 View from Range 1 Receiver Tower at 33-Foot Height

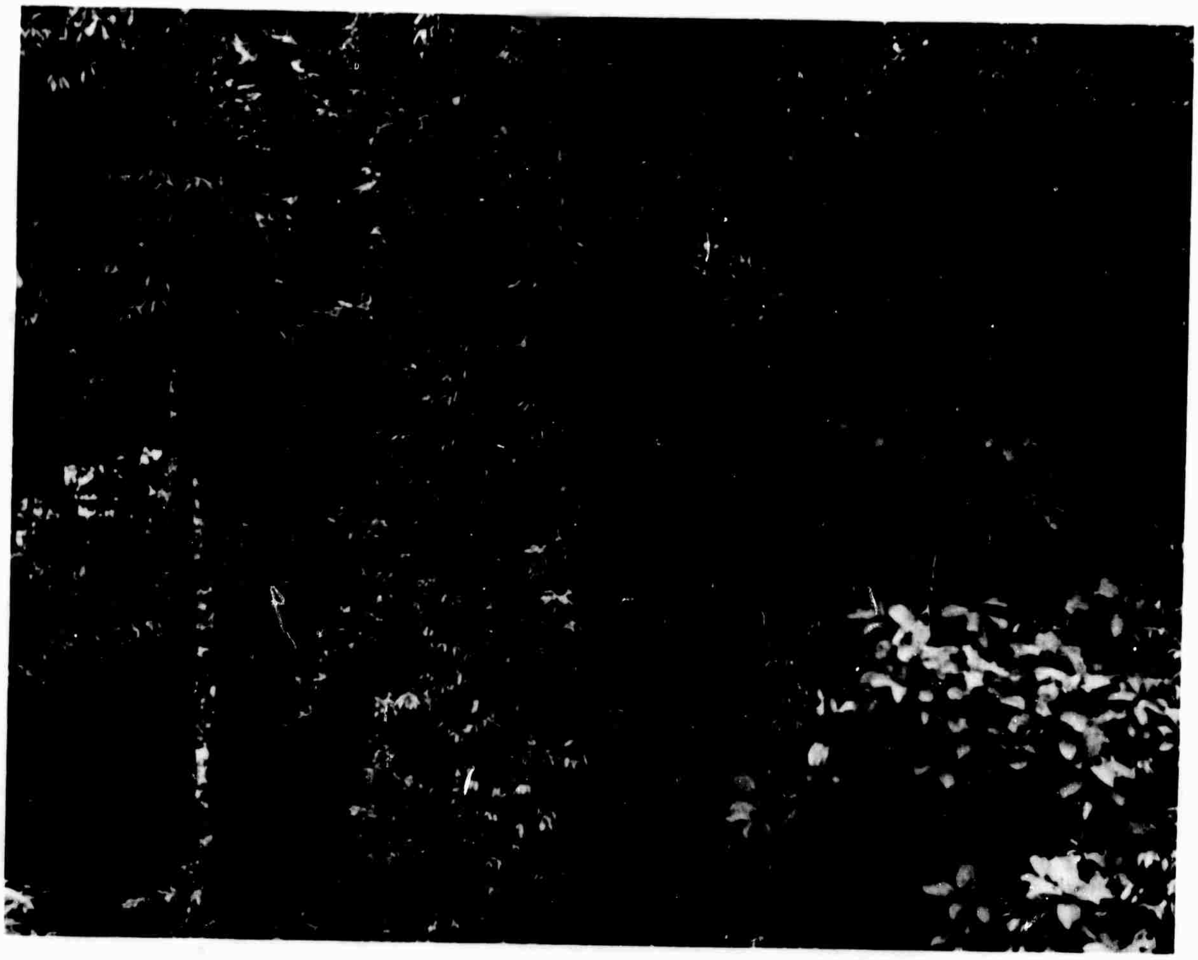


Figure 4.5 View from Range 1 Receiver Tower at 57-Foot Height

Figure 4.6 View from Range 1 Receiver Tower at 81-Foot Height

Figure 4.7 View from Range 1 Receiver Tower at 99-Foot Height

Views from Range 2 Receiver Tower

9-Foot Height

At this height, the foliage appears to be very dense. The closest foliage is the trunk of a tree located almost directly on the line of sight about 10 feet in front of the receiving antenna. Higher branches from this tree overhang the line of sight, but are probably too high to influence the transmission characteristics at this level. The foliage does not become dense for about 50 feet behind this tree. The transmitter tower is completely obscured at this height although glimpses of the sky are possible 5 to 10 degrees above the line of sight.

33-Foot Height

The foliage at this height appears very dense along the line of sight from approximately 15 feet in front of the receiving antenna. No light can be seen through the foliage in the direction of the line of sight, and the transmitting tower is completely obscured.

57-Foot Height

Thirty percent of the foliage is below this height and the nearest foliage is only 20 to 25 feet in front of the receiving antenna. Glimpses of obstacles behind the transmitter area can be had when looking below the line of sight, but no portion of the transmitting tower is visible. The majority of the foliage is on the transmitter side of the foliage slab.

81-Foot Height

Except for leafy branches from a tree a few feet to the left of the receiving tower, the line of sight is unobstructed by foliage for nearly 150 feet. Fifty percent of the trees are below this height, and the top of the

transmitter tower can be seen clearly through openings in the treetops. The rest of the tower including the 81-foot height is completely obscured by very dense foliage.

99-Foot Height

The upper section of the transmitter tower is visible from this height even though the line of sight is completely surrounded by foliage. Ninety percent of the foliage is below this height. Most of the foliage is on the transmitter side of the foliage slab. The nearest trees reaching to the line-of-sight level are 150 feet from the receiving tower.

4.2 Data Presentation

As mentioned previously, the total transmission distance between the transmitting and receiving antennas is 312 feet for Range 1 and 303 feet for Range 2. Since 60 feet of cleared area existed in front of the transmitting antenna, the foliage depth was 252 feet for Range 1 and 243 feet for Range 2. However, as indicated in the foliage descriptions, the foliage block often had long ranges which were free of obstacles. In some cases, the unobstructed path was as long as 150 feet even though it was considered within the foliage.

The free-space attenuations for the two transmission distances are given in Table 4.1.

Table 4.1

FREE-SPACE ATTENUATION FOR RANGES 1 & 2

Frequency (Gc/s)	Path Loss (dB) Range 1 (312 ft.)	Path Loss (dB) Range 2 (303 ft.)
0.55	66.8	66.5
1.00	72.0	71.7
2.50	79.9	79.6
5.00	86.0	85.7
10.00	92.0	91.7

The attenauation through the foliage was measured with all possible combinaticns of the following:

(1) transmission distance – 303 and 312 feet;

(2) height – 8, 33, 57, 81, and 99 feet above the ground:

(3) polarization – vertical and horizontal;

(4) frequency – 0.55, 1.00, 2.50, 5.00, and 10.00 Gc/s.

Note: Transmit and receive heights were identical, and no cross polarization measurements were made.

At each combination of range, height, polarization, and frequency, the attenuation was measured 10 times. For each of the 10 measurements the receiving antenna was moved to a different position in a plane normal to the direction of propagation. At every position the antenna was fixed and a 3- to 5-minute time recording was made. These positions were:

(1) center (indicated height above ground);

(2) 1 foot left of center;

(3) 2 feet left of center;

(4) 1 foot right of center;

(5) 2 feet right of center;

(6) 1 foot above center;

(7) 2 feet above center;

(8) 1 foot below center;

(9) 2 feet below center;

(10) repeat recording at the center position.

On each recording, the average signal level over the 3-5-minute run was estimated and the 10 values were averaged. The difference between this average value and the appropriate free-space attenuation is presented in Tables 4.2 and 4.3. Also presented in Tables 4.2 and 4.3 are the standard deviations of the 10 readings which were averaged.

The term "foliage attenuation" will be used for the difference between the average attenuation (in dB) and the free-space attenuation. The term "foliage attenuation rate" will be used to denote the ratio of the foliage attenuation to the foliage depth (i.e., in-foliage path length) in meters. Further discussion of these and other variables is given in Final Report Volume I.[8]

Table 4.2

FOLIAGE ATTENUATION AND ATTENUATION RATE ON RANGE 1

(Transmission Distance = 312 Feet
Foliage Depth = 252 Feet)

Antenna Height (ft)	Pol.	Freq. (Gc/s)	Foliage Atten. (dB)	Fol. Atten. Rate (dB/meter)	Standard Deviation (dB)
9	V	0.55	27.9	0.363	4.2
		1.00	26.3	0.343	2.9
		2.50	35.9	0.467	5.6
		5.00	36.4	0.475	4.3
		10.00	38.3	0.499	4.7
	H	0.55	14.1	0.183	3.8
		1.00	18.0	0.235	3.7
		2.50	31.3	0.408	5.9
		5.00	34.3	0.446	2.1
		10.00	43.3	0.564	4.2
			Ave=30.58		
33	V	0.55	15.1	0.197	5.2
		1.00	17.8	0.232	3.3
		2.50	25.2	0.328	4.7
		5.00	28.7	0.374	4.1
		10.00	34.9	0.455	6.7
	H	0.55	14.2	0.185	3.0
		1.00	15.2	0.197	5.1
		2.50	21.5	0.280	2.6
		5.00	32.9	0.428	3.6
		10.00	35.0	0.456	5.9
			Ave=24.14		
57	V	0.55	23.9	0.312	6.1
		1.00	14.0	0.182	2.0
		2.50	21.9	0.285	4.2
		5.00	31.4	0.409	2.8
		10.00	39.6	0.516	5.8
	H	0.55	16.9	0.220	4.2
		1.00	13.5	0.176	3.0
		2.50	28.9	0.377	5.6
		5.00	36.2	0.472	3.5
		10.00	42.5	0.553	3.6
			Ave=26.88		

Table 4.2, continued

Antenna Height (ft)	Pol.	Freq. (Gc/s)	Foliage Atten. (dB)	Fol. Atten. Rate (dB/meter)	Standard Deviation (dB)
81	V	0.55	21.1	0.274	5.6
		1.00	15.5	0.202	3.3
		2.50	31.1	0.405	4.4
		5.00	41.4	0.539	7.0
		10.00	43.6	0.568	4.6
	H	0.55	10.1	0.132	2.4
		1.00	13.1	0.170	4.6
		2.50	31.7	0.412	6.3
		5.00	42.9	0.558	4.7
		10.00	47.7	0.621	2.9
			Ave=29.82		
99	V	0.55	7.3	0.095	1.6
		1.00	7.9	0.104	2.5
		2.50	24.7	0.321	2.9
		5.00	13.6	0.177	1.4
		10.00	18.2	0.237	4.4
	H	0.55	8.3	0.109	1.2
		1.00	2.8	0.037	1.9
		2.50	24.8	0.323	6.5
		5.00	14.9	0.194	2.2
		10.00	18.8	0.245	4.6
			Ave=14.13		

Table 4.3

FOLIAGE ATTENUATION AND ATTENUATION RATE ON RANGE 2

(Transmission Distance = 303 Feet
Foliage Depth = 243 Feet)

Antenna Height (ft)	Pol.	Freq. (Gc/s)	Foliage Atten. (dB)	Fol. Atten. Rate (dB/meter)	Standard Deviation (dB)
9	V	0.55	32.5	0.439	3.7
		1.00	26.4	0.356	4.8
		2.50	42.9	0.580	4.0
		5.00	50.9	0.687	6.7
		10.00	NO DATA AVAILABLE		
	H	0.55	23.8	0.321	7.1
		1.00	26.7	0.360	7.6
		2.50	41.4	0.559	3.3
		5.00	59.0	0.797	3.7
		10.00	NO DATA AVAILABLE		
			Ave=37.95		
33	V	0.55	20.9	0.283	4.1
		1.00	22.6	0.305	6.7
		2.50	40.6	0.548	4.1
		5.00	42.0	0.567	3.2
		10.00	46.8	0.632	3.2
	H	0.55	9.3	0.126	1.0
		1.00	19.2	0.259	2.9
		2.50	37.6	0.508	4.5
		5.00	46.4	0.627	3.5
		10.00	60.8	0.821	6.0
			Ave=34.62		
57	V	0.55	23.9	0.323	5.4
		1.00	24.3	0.328	4.9
		2.50	38.8	0.525	6.5
		5.00	45.2	0.611	4.3
		10.00	51.5	0.696	5.6
	H	0.55	18.1	0.244	6.2
		1.00	20.7	0.280	5.6
		2.50	33.7	0.455	4.0
		5.00	47.0	0.634	6.2
		10.00	53.5	0.722	2.3
			Ave=35.67		

Table 4.3, continued

Antenna Height (ft)	Pol.	Freq. (Gc/s)	Foliage Atten. (dB)	Fol. Atten. Rate (dB/meter)	Standard Deviation (dB)
81	V	0.55	17.7	0.239	5.6
		1.00	10.1	0.136	1.9
		2.50	23.1	0.313	1.3
		5.00	21.5	0.291	5.1
		10.00	31.7	0.429	5.9
	H	0.55	10.6	0.143	2.9
		1.00	7.5	0.102	1.3
		2.50	23.2	0.314	0.9
		5.00	24.6	0.332	3.8
		10.00	35.9	0.485	5.0
			Ave=20.59		
99	V	0.55	2.6	0.035	0.9
		1.00	4.6	0.062	1.2
		2.50	0.3	0.004	0.0
		5.00	NO DATA AVAILABLE		
		10.00	1.9	0.026	0.5
	H	0.55	4.6	0.062	1.5
		1.00	4.8	0.065	1.1
		2.50	0.1	0.001	0.1
		5.00	0.8	0.011	0.0
		10.00	0.3	0.004	0.0
			Ave= 2.22		

The rationale for presenting the data in this manner is as follows. Assuming free-space conditions (i.e., spherical spreading) the magnitude of the electric field at a distance r from the source has the form

$$|E_0| = \frac{K_0}{r} \tag{1}$$

where K_o is scme constant.

Again assuming spherical spreading within the foliage, the magnitude of the electric field at the same distance r is given by

$$E_f = \frac{K_1}{r} e^{-\alpha(r - r_c)} \tag{2}$$

Here it has been assumed that the source is a distance r_c from the foliage and that the medium between the source and the foliage is lossless. If the power input, antenna gain, and impedance are the same, then

$$K_0 \approx K_1$$

Note that it has been assumed that the reflection coefficient at the clearing-foliage interface is negligible. From the definition of foliage attenuation, we have

$$\text{Foliage Attenuation (dB)} = 20 \log \frac{|E_o|}{|E_f|} \tag{3}$$

$$= 20\,\alpha\,(r - r_c) \log e$$

or (4)

$$\alpha = \frac{\text{Foliage Attenuation (dB)}}{8.686\,(r - r_c)} \quad \text{nepers/meter}$$

or (5)

$$\alpha = \frac{\text{Foliage Attenuation (dB)}}{(r - r_c)} \quad \text{dB/meter}$$

When comparing the standard deviations in Tables 4.2 and 4.3 of each combination of frequency, polarization, height and range, there does not seem to be any significant trend in the data, except the expected increase in standard deviation as the magnitude of the quantity being measured increases as shown in Figure 4.8. In other words, as the foliage becomes more dense, greater changes in the foliage attenuation can be expected for small changes in the location of the receiving antenna. This can also be stated in slightly different terms – as the foliage becomes more dense, it cannot be assumed that the foliage will appear to be more homogeneous in actual cases.

The fact that no significant trend exists in the standard deviations implies that changes in field strength due to small changes in antenna position will be equally great for horizontal and vertical polarizations from 0.55 to 10 Gc/s. This is shown in Figure 4.9.

Figure 4.10 is a graph of the foliage attenuation averaged over all frequencies and polarizations for each range versus height above ground. By comparing Figure 4.10 with the foliage descriptions in Section 4.1.2, it seems that this average foliage attenuation is a rough measure of the foliage density over a particular path. Note that over Range 1, average foliage attenauation gradually increases as the height is varied from 33 feet to 57 feet and then to 81 feet. In the foliage descriptions for this range, the foliage was described as "not very dense" at 33 feet, "rather dense" at 57 feet and "in the midst of the foliage canopy ... very dense" at 81 feet. At the 99-foot height, Range 1 has about 12 dB more attenuation than Range 2. Comparison of the foliage descriptions for these heights indicates that the attenuation would be expected to be greater for Range 1 than for Range 2. On Range 1 the "... tower is clearly visible through the branches of these large trees," and on Range 2 the "... tower is visible from this height even though the line of sight is completely surrounded

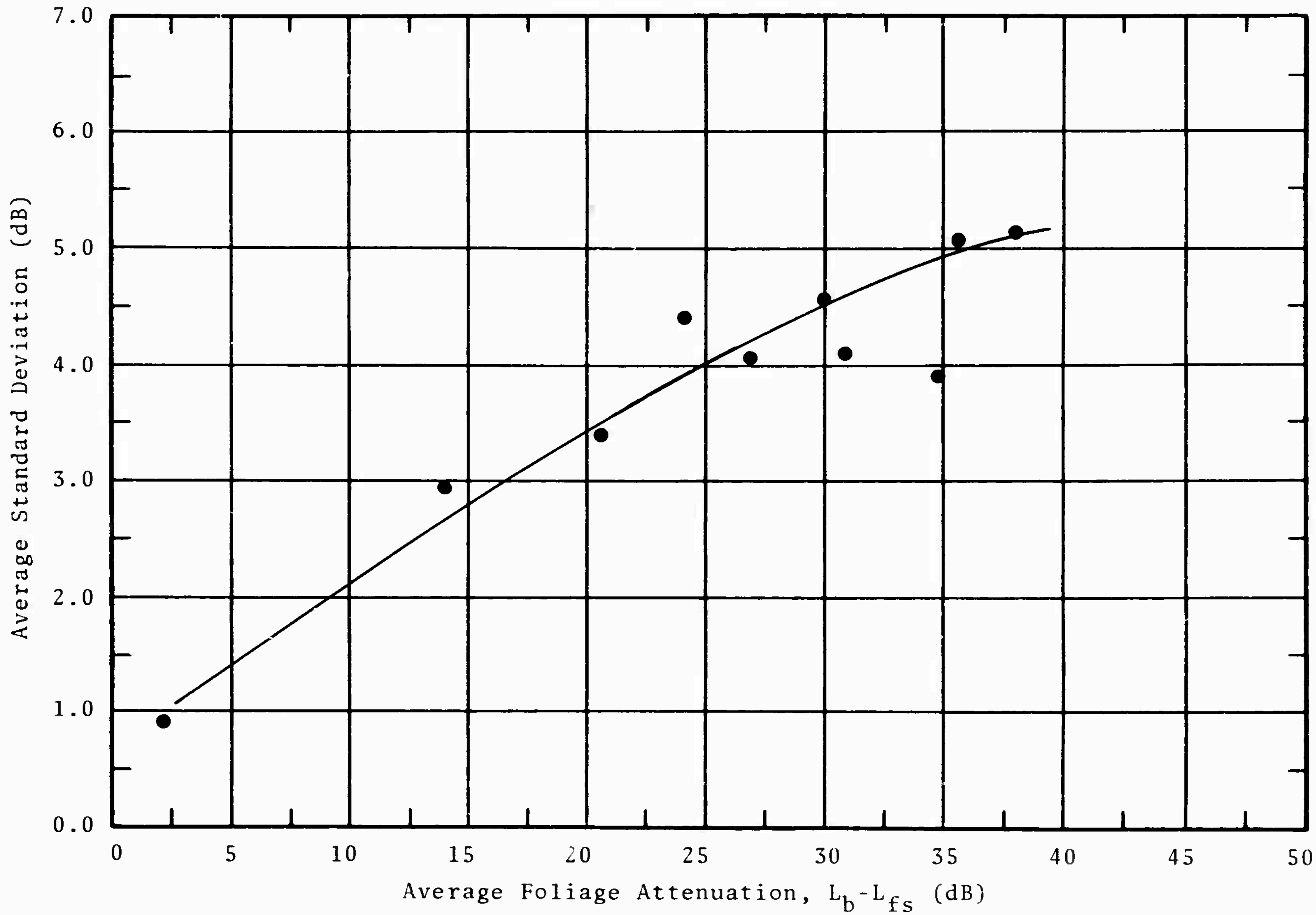


Figure 4.8 Standard Deviation Versus Average Foliage Attenuation for Each Antenna Height and Range Combination

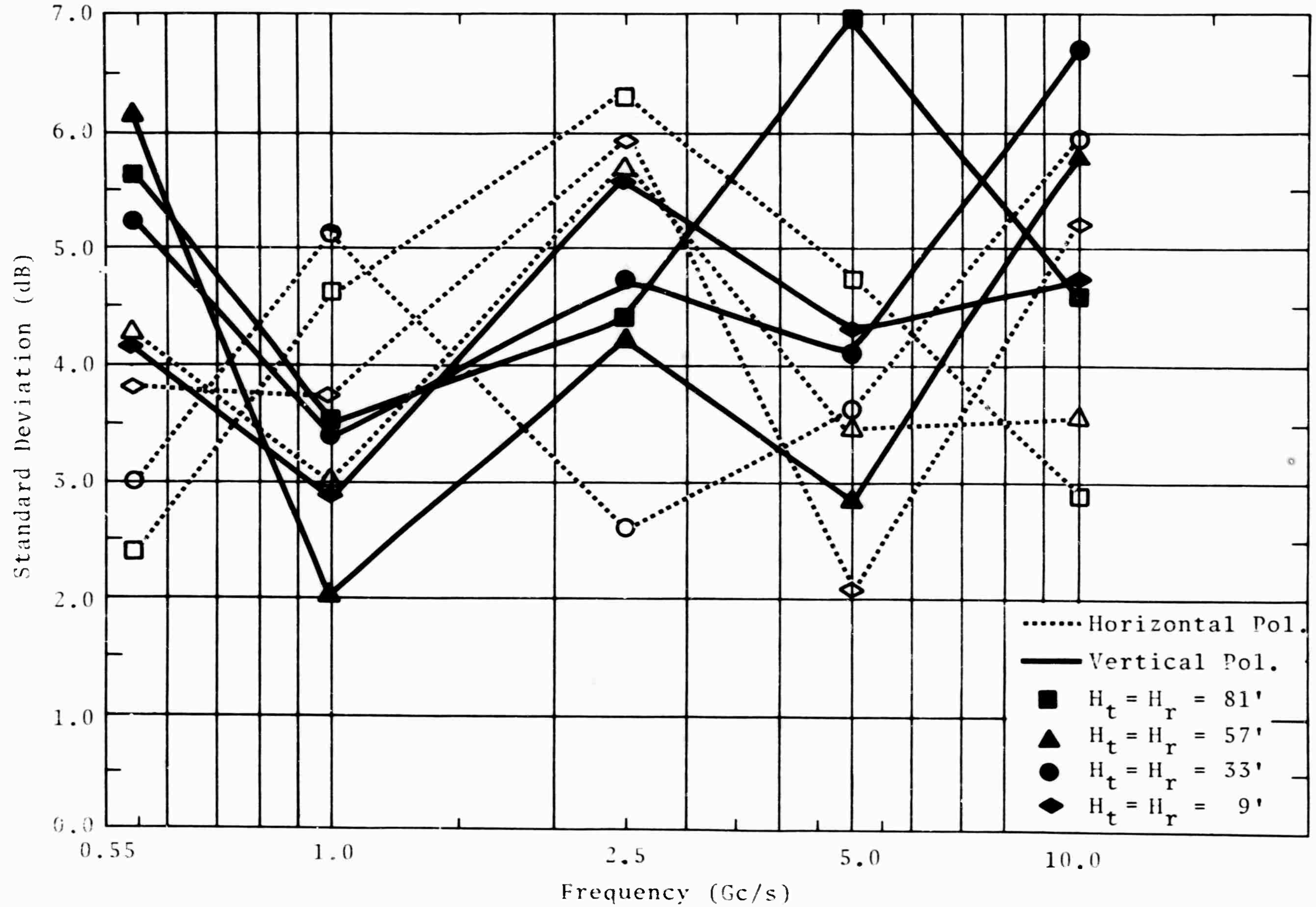


Figure 4.9 Standard Deviation Versus Frequency for Path Losses at 10 Antenna Positions Within a 2-Foot Radius

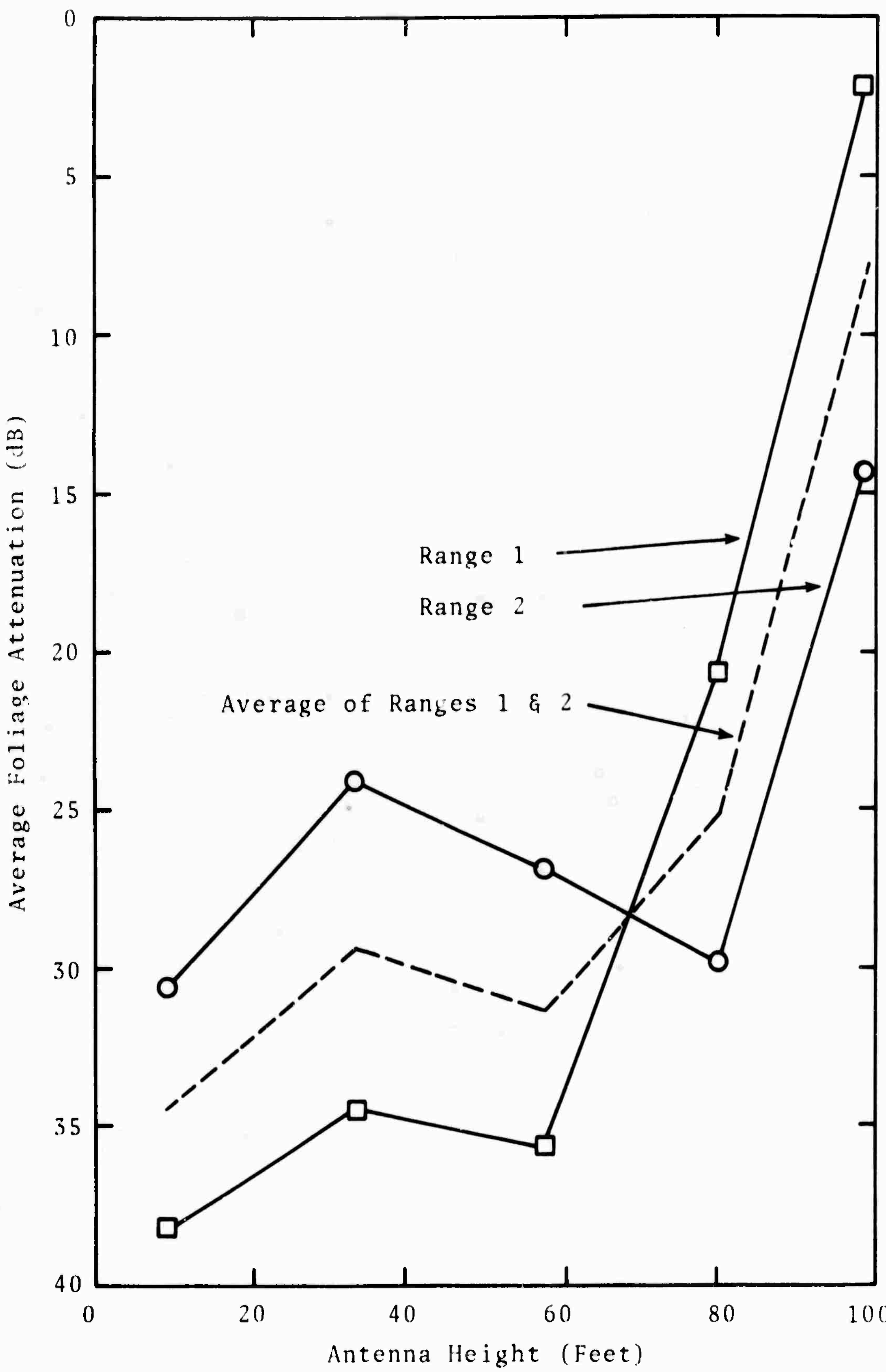


Figure 4.10 Average Foliage Attenuation Versus Antenna Height

by foliage." Thus, there seems to be some correlation between the average foliage attenaution at the various heights and the density of the foliage. Only one exception can be noted – even though the average foliage attenuation on Range 1 is quite high at 9 feet, the foliage description states that the foliage is "not very dense at this level, ..."

4.3 Data Analysis

It would be desirable to investigate the relationship between the foliage attenuation and the foliage density. Since the average foliage attenuation is the only available measure of the foliage density, relationships between the actual foliage attenuation and the average foliage attenuation will be studied.

The data is not analyzed for distance, antenna height or polarization dependence. The two ranges used have a total transmission distance of 312 feet (for Range 1) and 303 feet (for Range 2). The difference in these distances is so small that the dependence of the variables on the range is, at best, very inaccurate. In reality, the effect of changing the range is to change the foliage density. Thus, different height and range combinations can be interpreted as simply changing the foliage density. The data also could not be analyzed as a function of the polarization since only vertical and horizontal polarizations were used. Therefore, when plotting the data, different curves have been used for vertical and horizontal polarizations.

Thus, it can be seen that the relationship of foliage attenuation to foliage density (i.e., average foliage attenuation), frequency, and polarization must be determined. This relationship can be expressed mathematically as

$$A_f = g\,(\bar{A}_f, F, P) \qquad (6)$$

where

$A_f =$ foliage attenuation

$g \rightarrow$ some functional relationship

$\bar{A}_f =$ average foliage attenuation for each range and antenna height combination

F = frequency

P = polarization

From the above functional relationship we could also derive expressions for the advantage of one polarization over another, [i.e., $A_f(V)/A_f(H)$], and for foliage attenuation ratios.

Figures 4.11 through 4.14 present the foliage attenuation and the foliage attenuation rate versus the logarithm of frequency. Each figure presents data for a different range and polarization. In each case, the method of least squares was used to determine a linear regression line which would fit the data the best. The best fit is created when the root-mean-square of the vertical distance between the data points and the regression line is minimized. The result of each fit was an intercept and slope for the best regression line and an RMS value of the vertical distance between the data points and the regression line. Table 4.4 presents the results of the best linear fits when they were applied to the data in Figures 4.11 through 4.14.

These slopes of the frequency dependence are plotted in Figure 4.15 as a function of the average foliage attenuation at each combination of range and height. In this figure, the data seems to follow two separate trends – one for vertical polarization and the other for horizontal. The best fit to these two trends is as follows:

Vertical polarization slope

$$b_V = -0.0019 + 0.6674\ \bar{A}_f \tag{7}$$

Horizontal polarization slope

$$b_H = -0.4076 + 0.9559\ \bar{A}_f \tag{8}$$

where $\bar{A}_f$ is the average foliage attenuation in decibels as shown in Figure 4.10.

The intercepts of the frequency dependence are plotted in Figure 4.16 as a function of the average foliage attenuation for each range and height combination. Again in this figure, the data follows two distinct trends identical to Figure 4.15. The best linear regression lines are:

Table 4.4

SLOPES AND INTERCEPTS OF FOLIAGE ATTENUATION VERSUS LOGARITHM OF FREQUENCY

Range	Height (ft)	Pol.	Slope (dB/decade)	Intercept (dB)
1	9	V	9.87	29.34
		H	23.35	19.63
	33	V	15.75	18.59
		H	18.53	16.95
	57	V	15.38	20.52
		H	23.28	19.06
	81	V	22.47	22.28
		H	32.89	17.00
	99	V	8.92	11.05
		H	10.89	9.94
2	9	V	22.72	33.41
		H	37.06	29.96
	33	V	22.48	26.32
		H	40.51	19.80
	57	V	23.94	27.97
		H	30.28	23.48
	81	V	12.63	16.20
		H	21.43	12.54
	99	V	-1.43	2.76
		H	-4.04	3.61

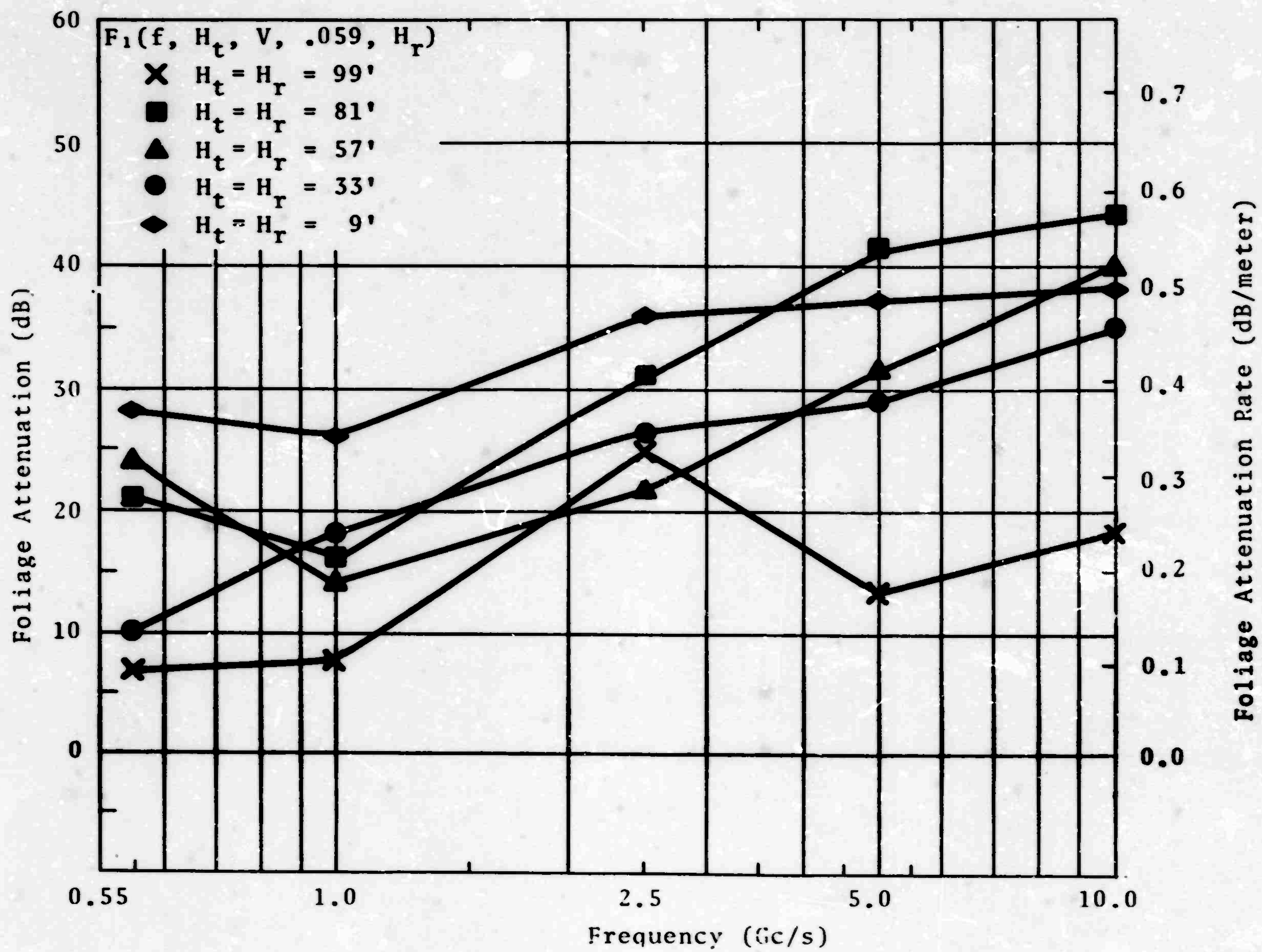


Figure 4.11 Foliage Attenuation and Attenuation Rate Versus Frequency for Range 1

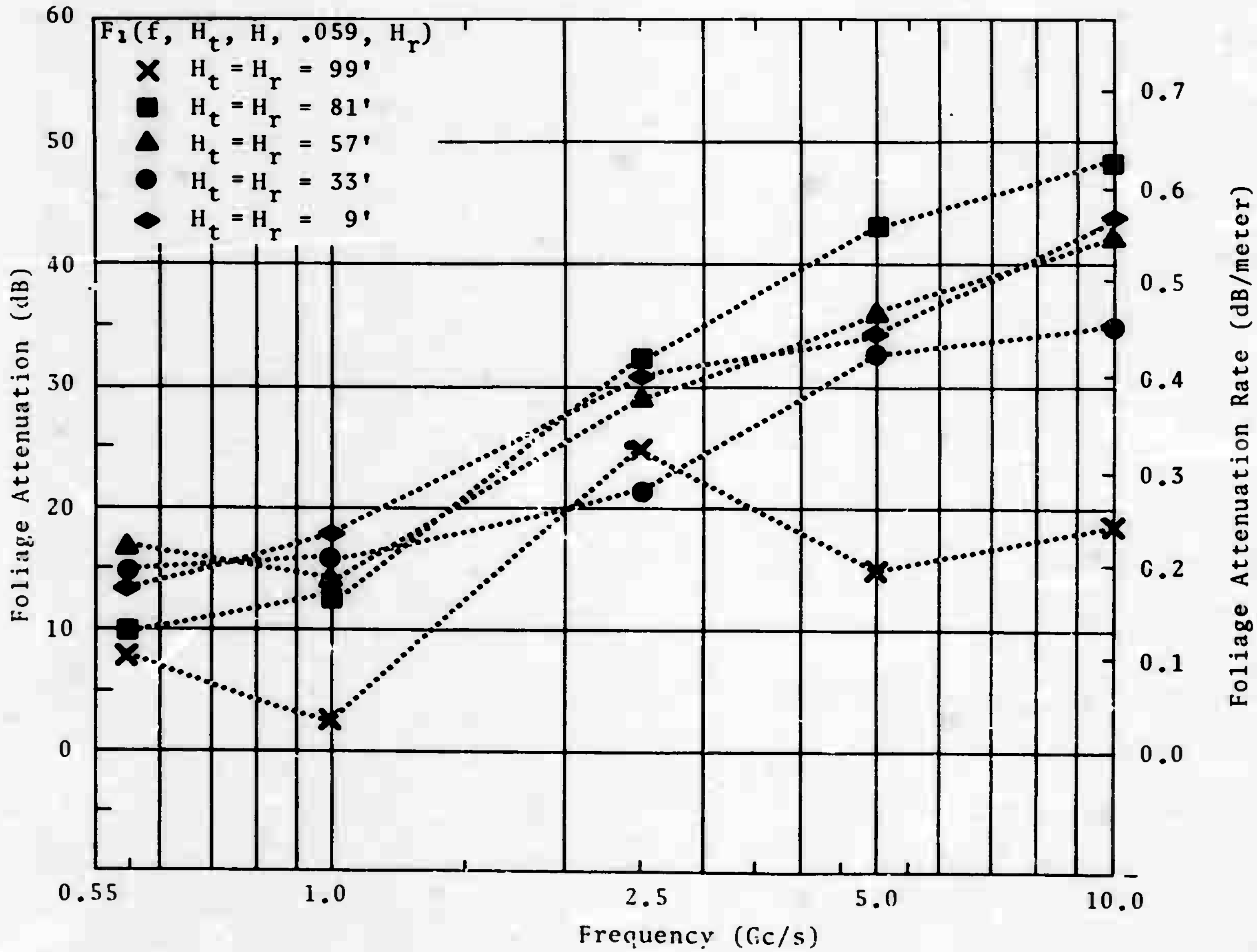


Figure 4.12 Foliage Attenuation and Attenuation Rate Versus Frequency for Range 1

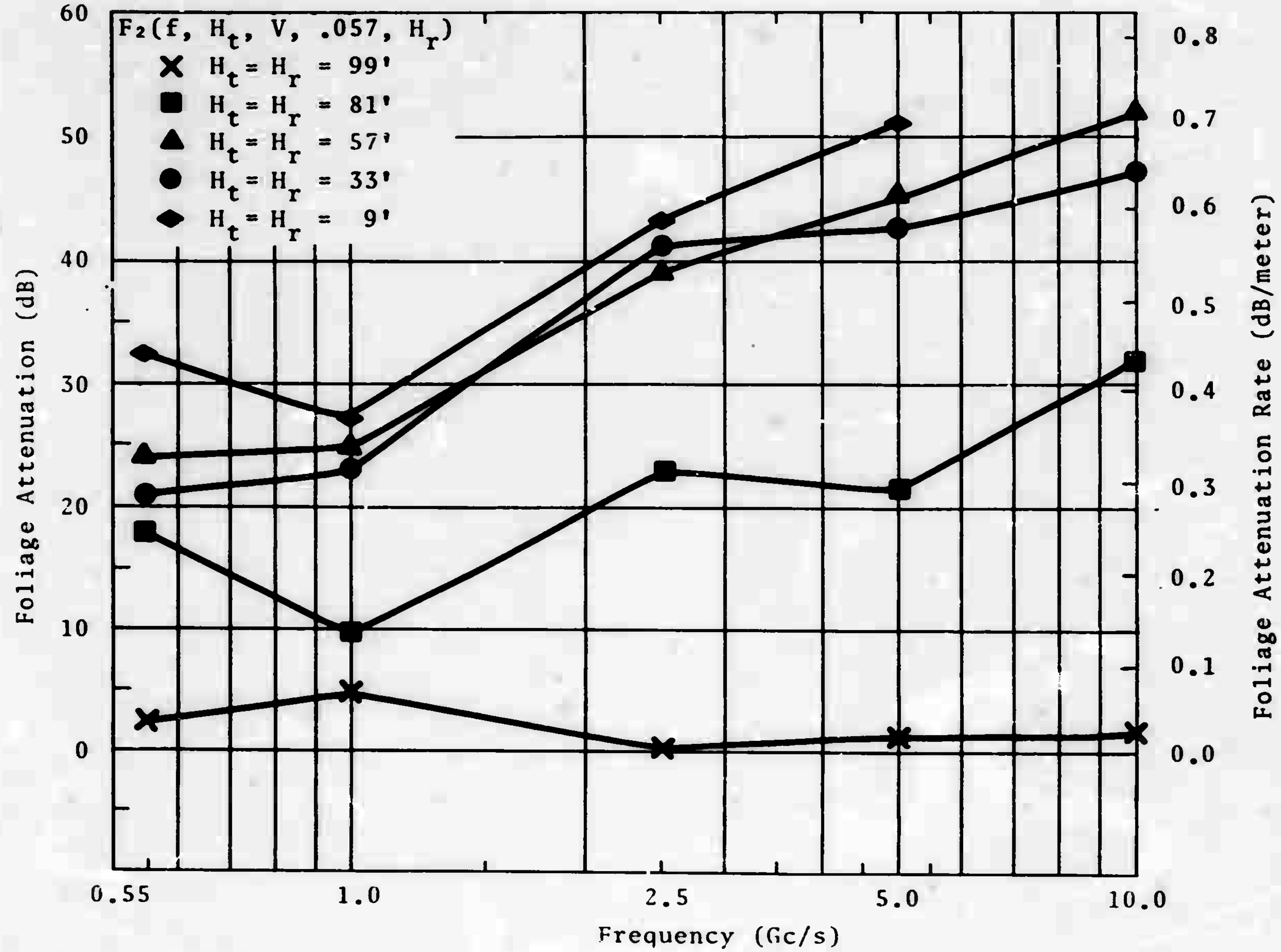


Figure 4.13 Foliage Attenuation and Attenuation Rate Versus Frequency for Range 2

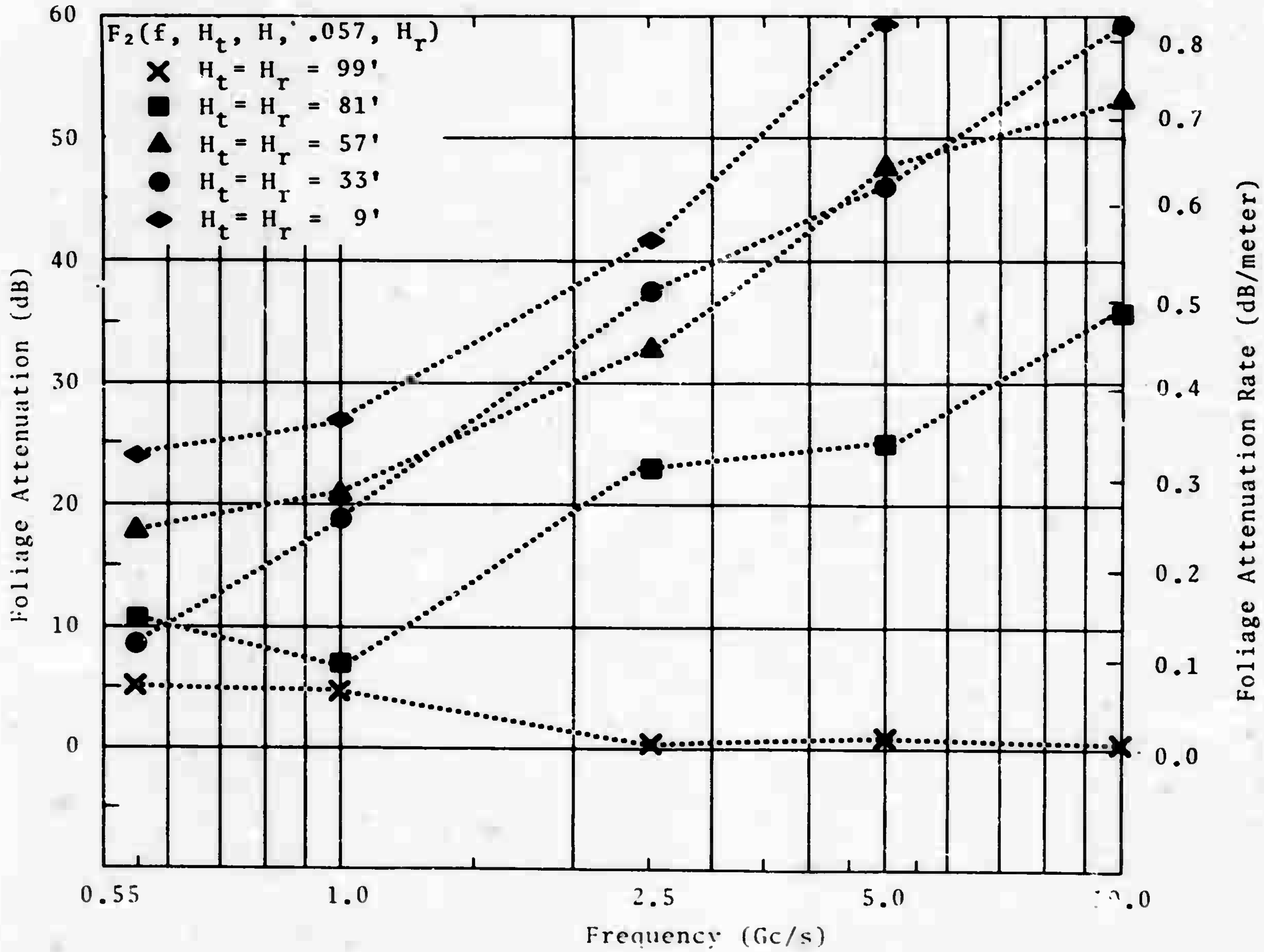


Figure 4.14 Foliage Attenuation and Attenuation Rate Versus Frequency for Range 2

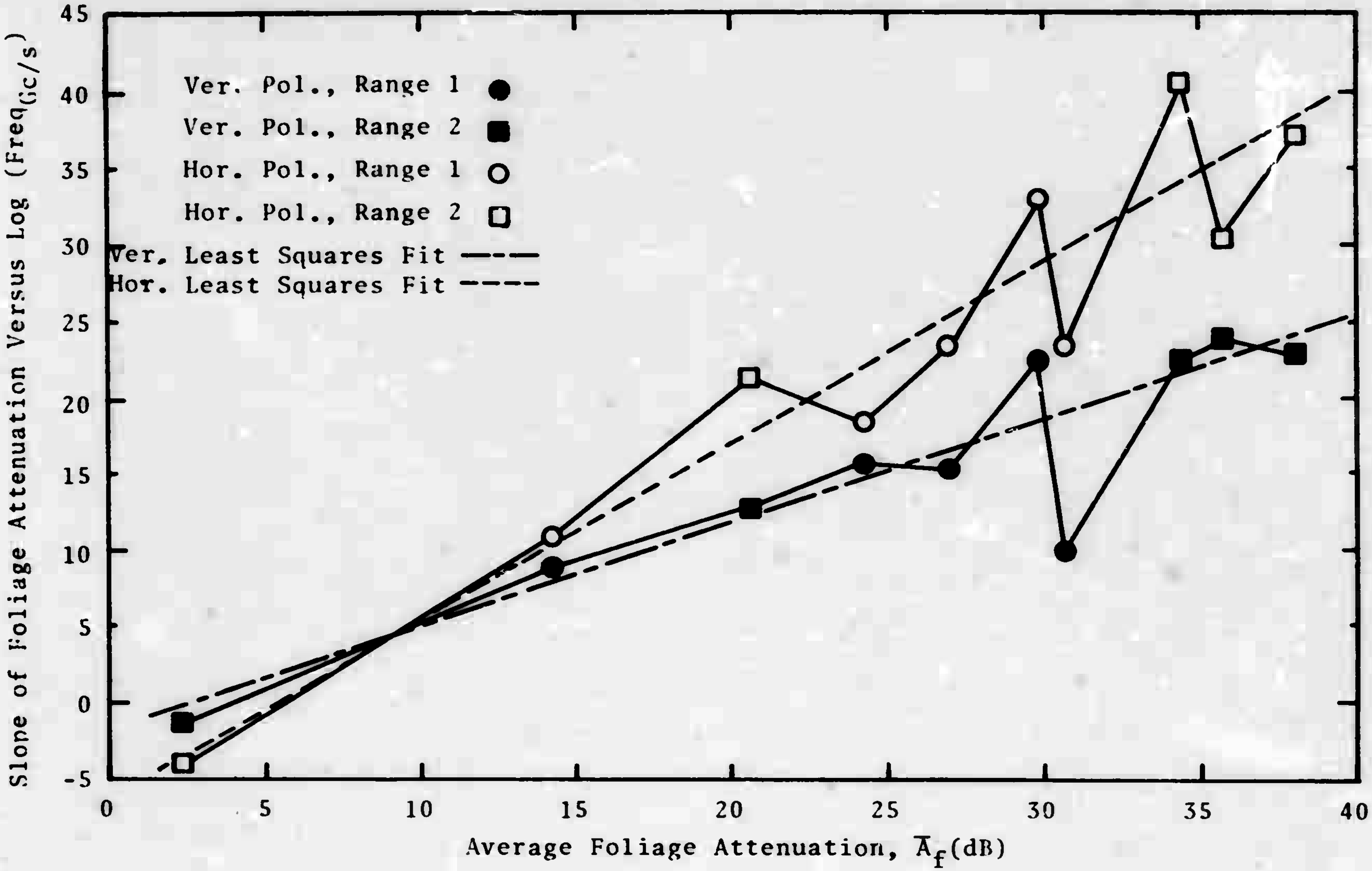


Figure 4.15 Slope of Logarithmic Frequency Dependence of Foliage Attenuation Versus Average Foliage Attenuation

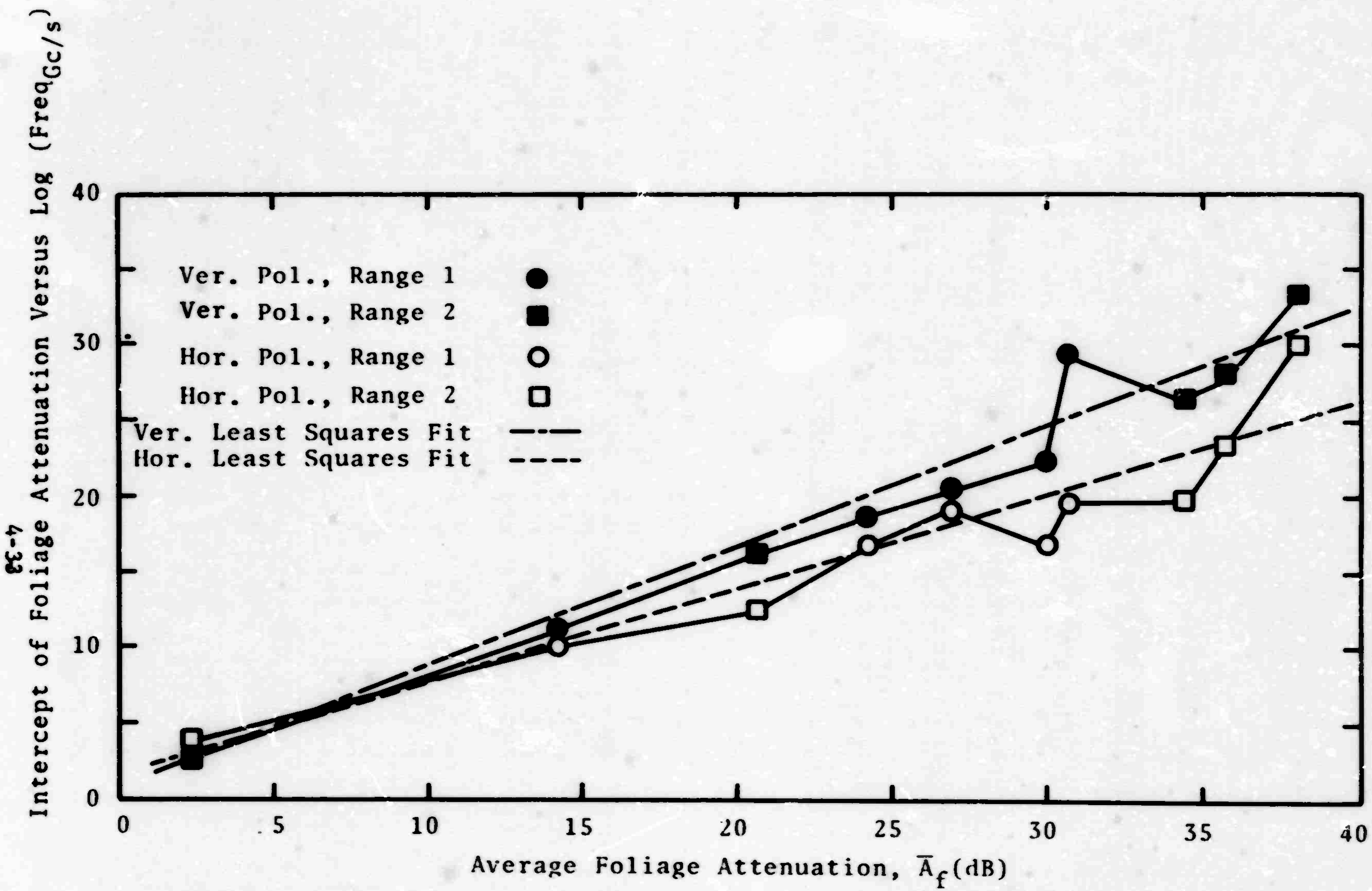


Figure 4.16 Intercept of Logarithmic Frequency Dependence of Foliage Attenuation Versus Average Foliage Attenuation

Vertical polarization intercept

$$a_V = -0.1972 + 0.8167\,\bar{A}_f \tag{9}$$

Horizontal polarization intercept

$$a_H = +1.0292 + 0.6290\,\bar{A}_f \tag{10}$$

Combining the above equations results in expressions for the foliage attenuation, A_f, as a function of the frequency, $(F_{Gc/s})$, and the average foliage attenuation, A_f. Note that A_f is a function of height as shown in Figure 4.10.

For vertical polarization

$$\begin{aligned} A_f = 0.1972 + 0.8167\,\bar{A}_f &- 0.0019 \log (F_{Gc/s}) \\ &+ 0.6674\,\bar{A}_f \log (F_{Gc/s}) \end{aligned} \tag{11}$$

For horizontal polarization

$$\begin{aligned} A_f = 1.0292 + 0.6290\,A_f &- 0.4076 \log (F_{Gc/s}) \\ &+ 0.9559\,\bar{A}_f \log (F_{Gc/s}) \end{aligned} \tag{12}$$

where $F_{Gc/s}$ = frequency in gigacycles per second

If the additional constraint is imposed that the computed foliage attenuation must equal zero when the average foliage attenuation is zero, then the intercept of the slope versus average foliage attenuation and the intercept of the intercept versus average foliage attenuation must be zero. This changes the slopes of these graphs slightly and the following equations result.

For vertical polarization

$$A_f = 0.812\,\bar{A}_f + 0.595\,\bar{A}_f \log (F_{Gc/s}) \tag{13}$$

For horizontal polarization

$$A_f = 0.670\,\bar{A}_f + 0.944\,\bar{A}_f \log (F_{Gc/s}) \tag{14}$$

Equations 13 and 14 cannot be interpreted as an accurate prediction of the foliage attenuation in tropical jungles in all circumstances. Before applying these equations to other propagation paths, the reader must recall the circumstances under which the data was obtained. The following are two precautions which are used here only to illustrate circumstances where the equations are not useful.

(1) Equations 13 and 14 represent a modified least-squares-fit to data taken through foliage whose depth was 252 feet and 243 feet. No data has been taken in Area II which would or would not substantiate the validity of these equations in cases where the foliage depths are drastically different than the above.

(2) Equations 13 and 14 are based on measurements in a heavily foliated area. When the density of the foliage approached zero ($\bar{A}_f \to 0$), the antenna heights and antenna beamwidths were such that the effect of the ground could be neglected. Thus, equations 13 and 14 could not be expected to yield valid results when the propagation path is near the ground even though the foliage was very sparse (i.e., in a meadow, etc.).

The accuracy to which equations 13 and 14 are expected to predict the foliage attenuation is illustrated in Figure 4.17. The data presented in Tables 4.2 and 4.3 were compared with values computed from equations 13 and 14. The computed values were within ± 3 decibels of the measured value 50 percent of the time and within ± 6 decibels of the measured value 84 percent of the time.

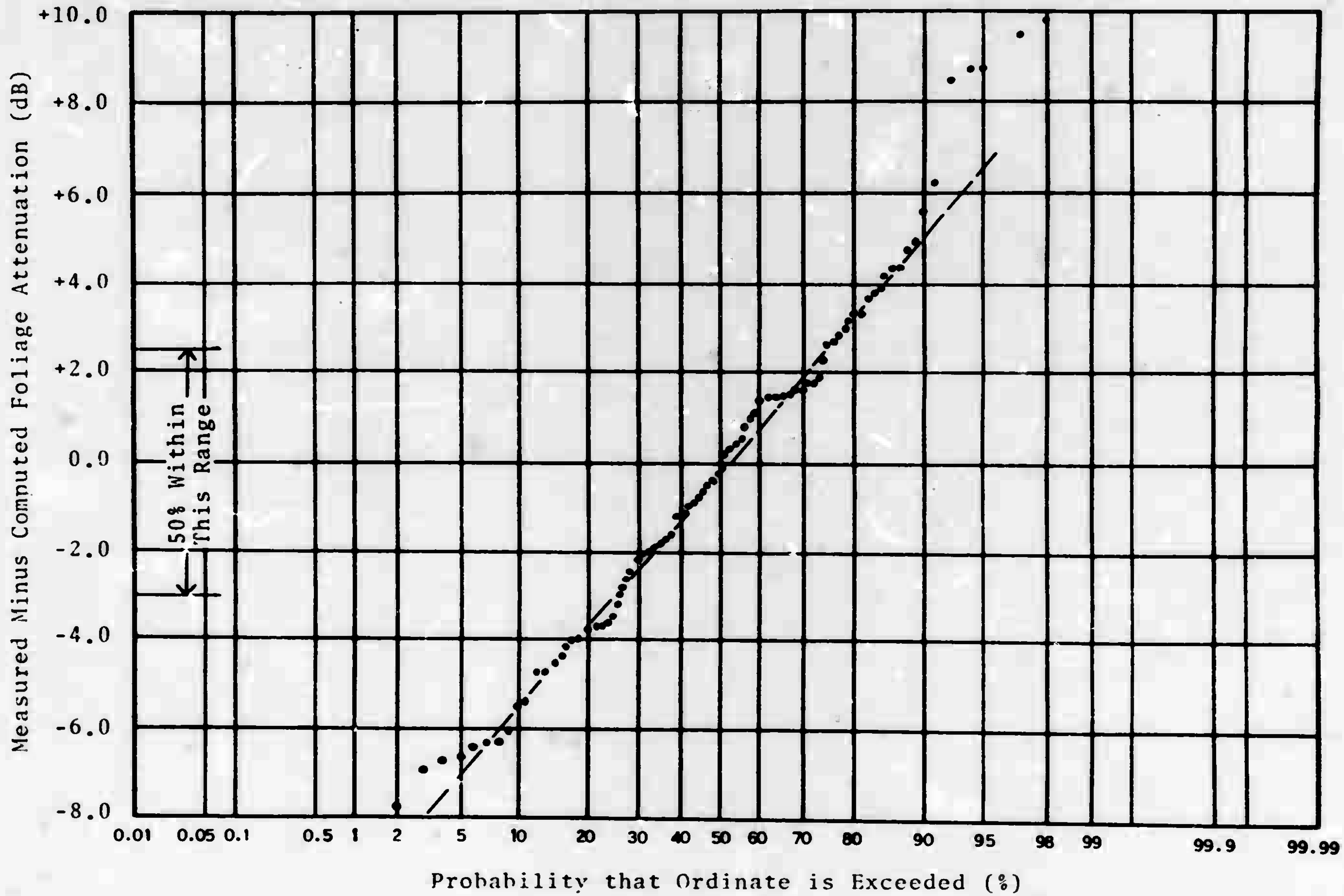


Figure 4.17 Comparison of Equations 13 and 14 with Measured Foliage Attenuation

5. TOWER TESTS

A series of measurements has been completed of propagation from tower-mounted transmitting antennas high above the jungle to receiving antennas near ground level. The results of this measurement series are called "tower data," part of which has been reduced and is presented in this section. There will be future studies of a similar nature involving transmissions between fixed, ground-based antennas and aircraft-mounted antennas.

5.1 Operational Procedures

The procedures used to collect the tower data are based on those developed for the walking data. A full description of the walking data procedures is in a previous project report.[4] One difference between those procedures and the tower data procedures was due to the higher transmitting antenna positions, since the tower that supports the 160- and 200-foot-high transmitting antennas occupied a different location. The same radial measurement trails have been used, with one exception. Radial X was discarded because the clearing for the airplane landing strip passes through it. A new trail, called Radial V, was prepared and substituted for it. The locations of the trails and the transmitting antenna tower are shown in Figure 5.1.

The 160- and 200-foot-high transmitting heights permit a clear line-of-sight path to the jungle top above the receiving antenna. The view along radial Z from a 120-foot elevation at the top of the AB/216 tower structure is shown in Figure 5.2. The means of attaining 160- and 200-foot transmitting heights with this tower and a tubular antenna mast is illustrated in Figure 5.3. Figure 5.4 is a photograph of the tower in its transmitting location. This tower system constitutes the only piece of equipment differing from that which was used in the previously reported walking measurements.

The hand-carried receiving antenna center is in all cases elevated to 6 feet above the ground. At the lowest frequency, 25 Mc/s, the receiving antenna is a small loop. For the higher frequencies resonant dipoles are used. Descriptions of the receiving and transmitting equipment, including the AB/216 tower and tubular antenna mast, can be found in a previous project report.[6]

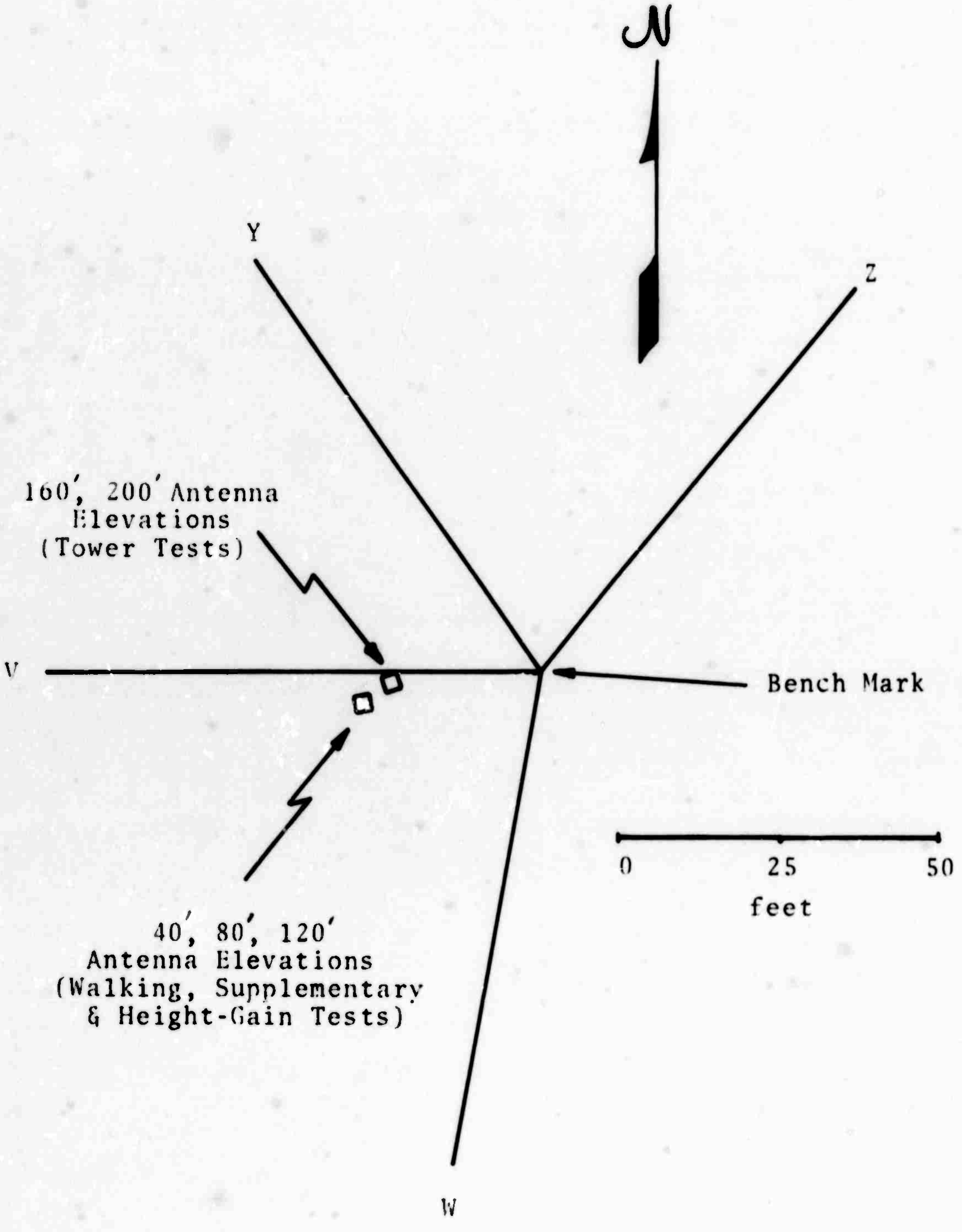
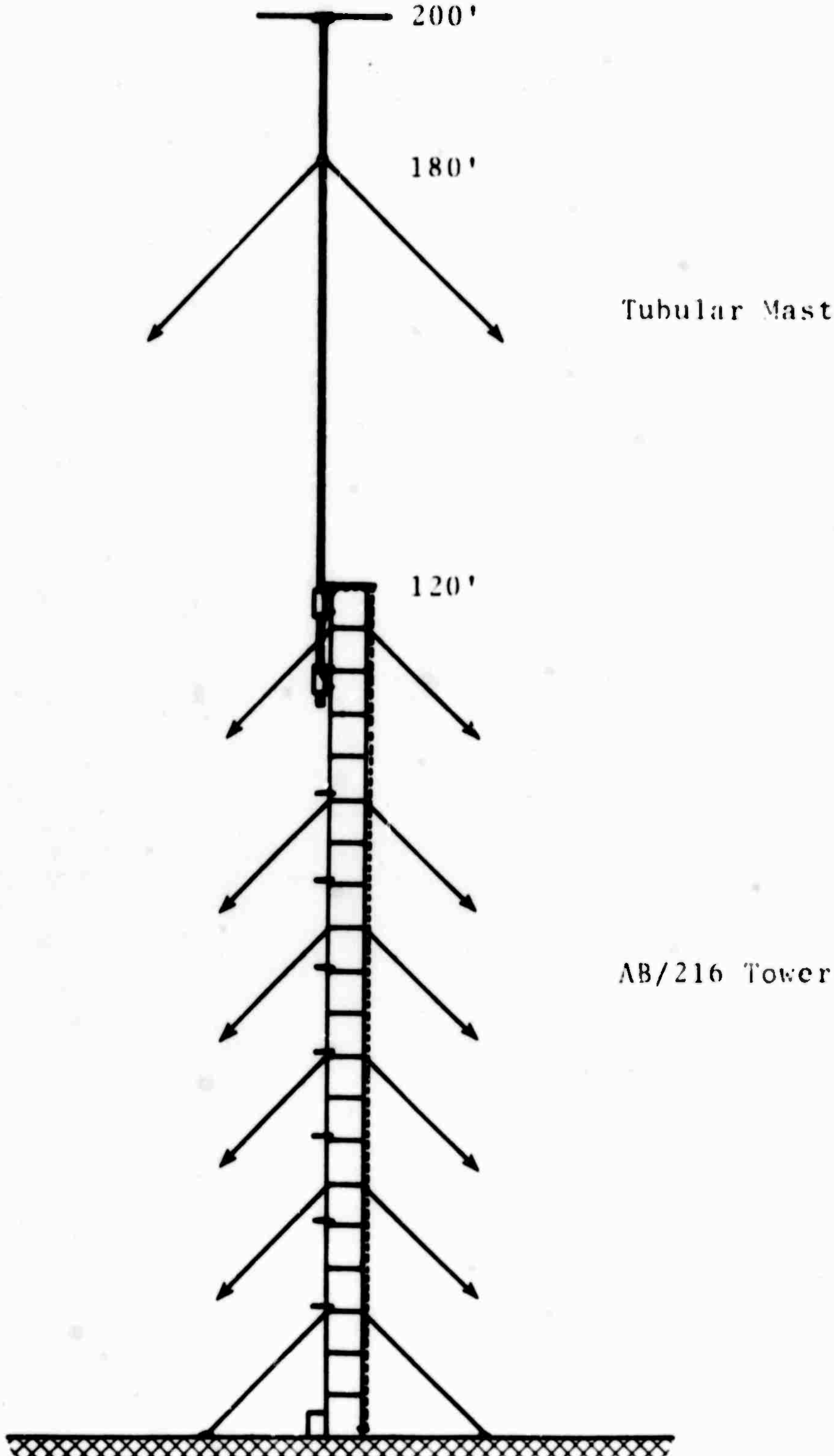


Figure 5.1 Trail Orientations and Transmitting Antenna Location for Tower Measurements

Figure 5.2 Radial Z as Seen from 120-Foot Level of Transmitting Tower



Scale

1 mm = 1 ft.

Figure 5.3 AB/216 Tower with Tubular Mast in Fully Raised Position

Figure 5.4 Photograph of Antenna Tower and Mast in Transmitting Position

The measurement points along each radial trail have numbers which, when multiplied by 100, give their distance in feet from the bench mark at the center of the trails. The spacing between points along the radials is 50 feet for points numbered through 10.0, 100 feet for points numbered 10.0 through 25.0, 200 feet for points numbered 25.0 through 49.0, and 500 feet for points numbered 49.0 through 74.0.

The computer program for reducing the measurements to basic transmission loss has been modified to correct for antenna patterns. Since the elevation angles from receiver to transmitter vary from about 1 degree to 45 degrees, this correction is required for conformity with the definitions of basic transmission loss. The transmitting antennas are resonant dipoles which, when oriented for vertical polarization, require a pattern correction. The vertical dipoles used to receive at frequencies above 25 Mc/s need the same correction. The only correction needed when using horizontal polarization is for the receiving loop antenna used at 25 Mc/s. The expressions for the different correction factors are listed below.

(1) Vertical polarization, frequency = 25 Mc/s:

$$F(\alpha) = \frac{\cos(\pi/2 \sin \alpha)}{\cos \alpha}$$

(2) Vertical polarization, frequency > 25 Mc/s:

$$F(\alpha) = \frac{\cos(\pi/2 \sin \alpha)}{\cos \alpha} \quad \frac{\cos(\pi/2 \sin \alpha)}{\cos \alpha}$$

(3) Horizontal polarization, frequency = 25 Mc/s:

$$F(\alpha) = \cos \alpha$$

(4) Horizontal polarization, frequency > 25 Mc/s:

$$F(\alpha) = 1.0$$

where

α = elevation angle between transmitter and receiver

$F(\alpha)$ = two-antenna transmission factor in terms of relative field strength

5.2 Tower Data

The data presented in this section is derived from measurements made along Radial Z at frequencies of 25, 50, 100, 250, and 400 Mc/s, for both vertical and horizontal polarizations. The transmitting antenna height was 160 feet.

The measurements made at the different points along Radial Z are presented graphically in Figures 5.5a to 5.14a. Each figure represents a different frequency and polarization combination. The maximum and minimum path losses recorded within 10 feet of a measurement point are shown, and each of these path loss pairs is graphed at its radial distance from the transmitting antenna tower.

Graphs of this data have been visually compared to the corresponding graphs of walking data taken six months earlier with a tower height of 120 feet on Radial Z. In each case the 160-foot tower data appeared to have a basic transmission loss that was a few dB less than that for the 120-foot tower height, with one exception: The new basic loss curves for vertical polarization at 25 Mc/s appeared to have equal or greater loss on the average than previous curves. The standard deviation of the previous data was about 6 dB.

In addition to the standard measurements at fixed points along the trails, a continuous recording of field strength versus radial distance has been taken at radial point number 25.0 (2500 feet from the bench mark). This recording was obtained by carrying the receiving antenna at approximately constant velocity over a 50-foot distance extending from 25 feet in front of point number 25.0 to 25 feet beyond it. The data is presented as recorded in the field in the Figures 5.5b to 5.14b, each of which follows its corresponding graph.

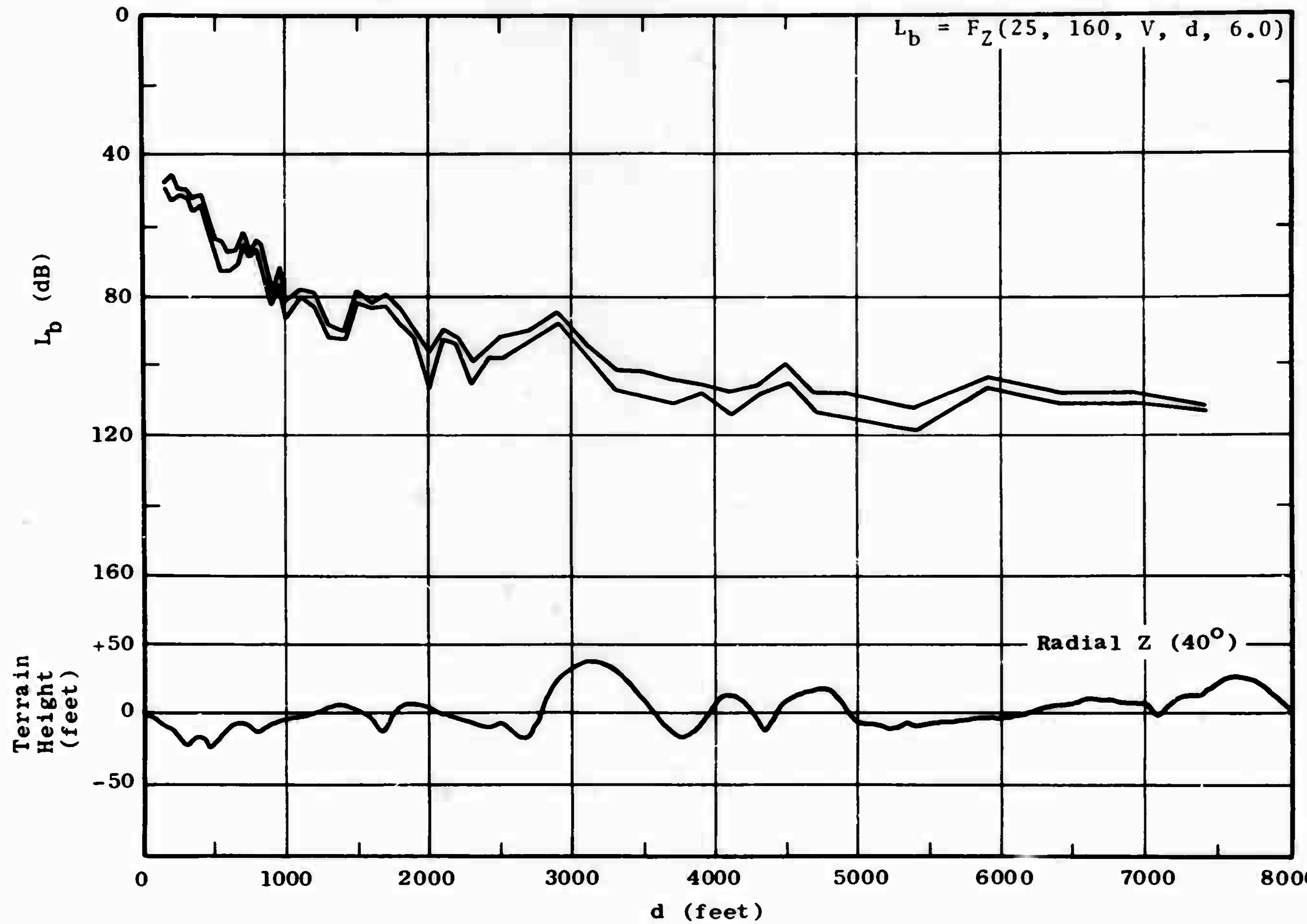


Figure 5.5a Maximum and Minimum Basic Transmission Loss as a Function of Distance

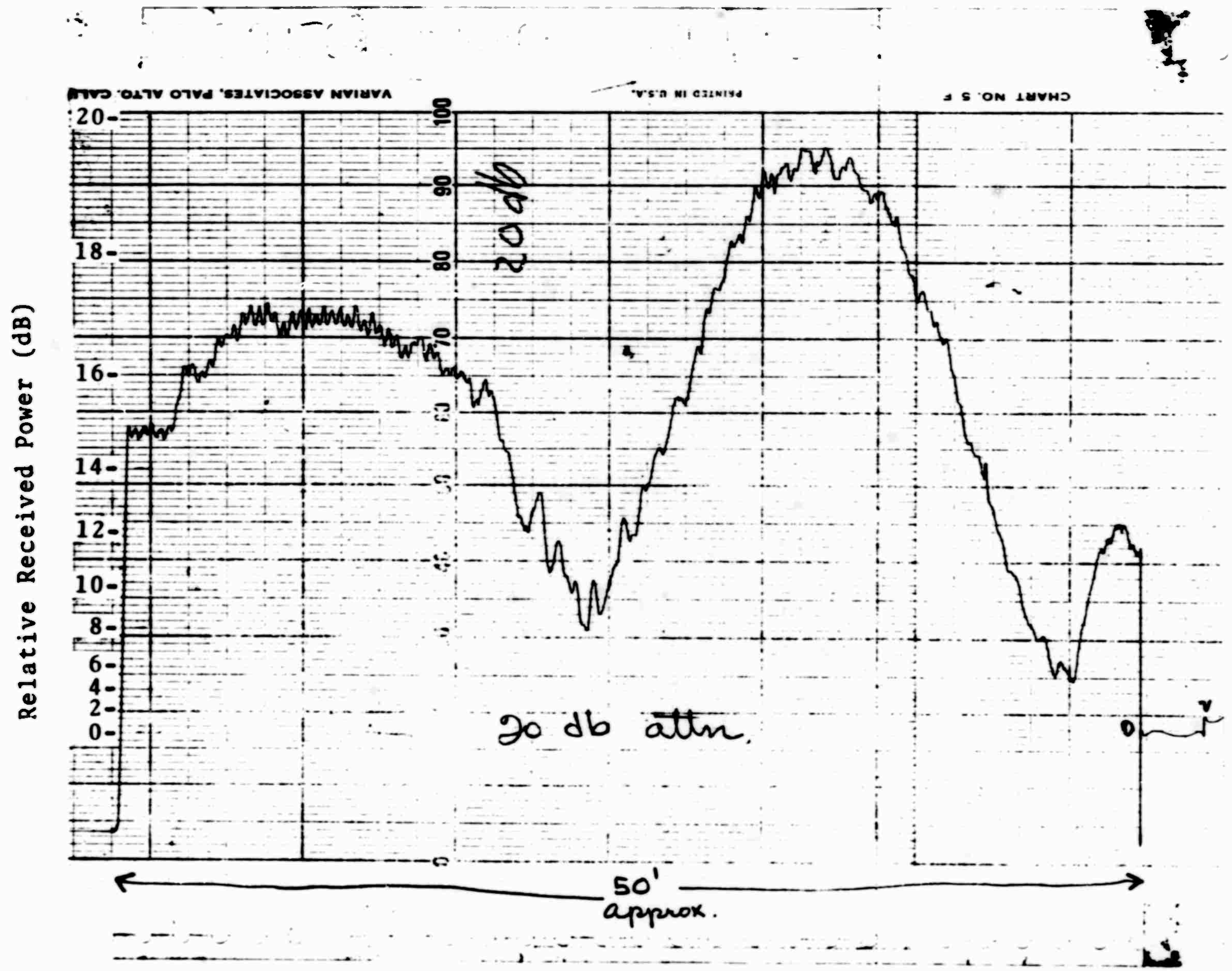


Figure 5.5b Continuous Recording of Received Power Over a 50-Foot Distance
$F_Z(25, 160, V, .473, 6.0)$

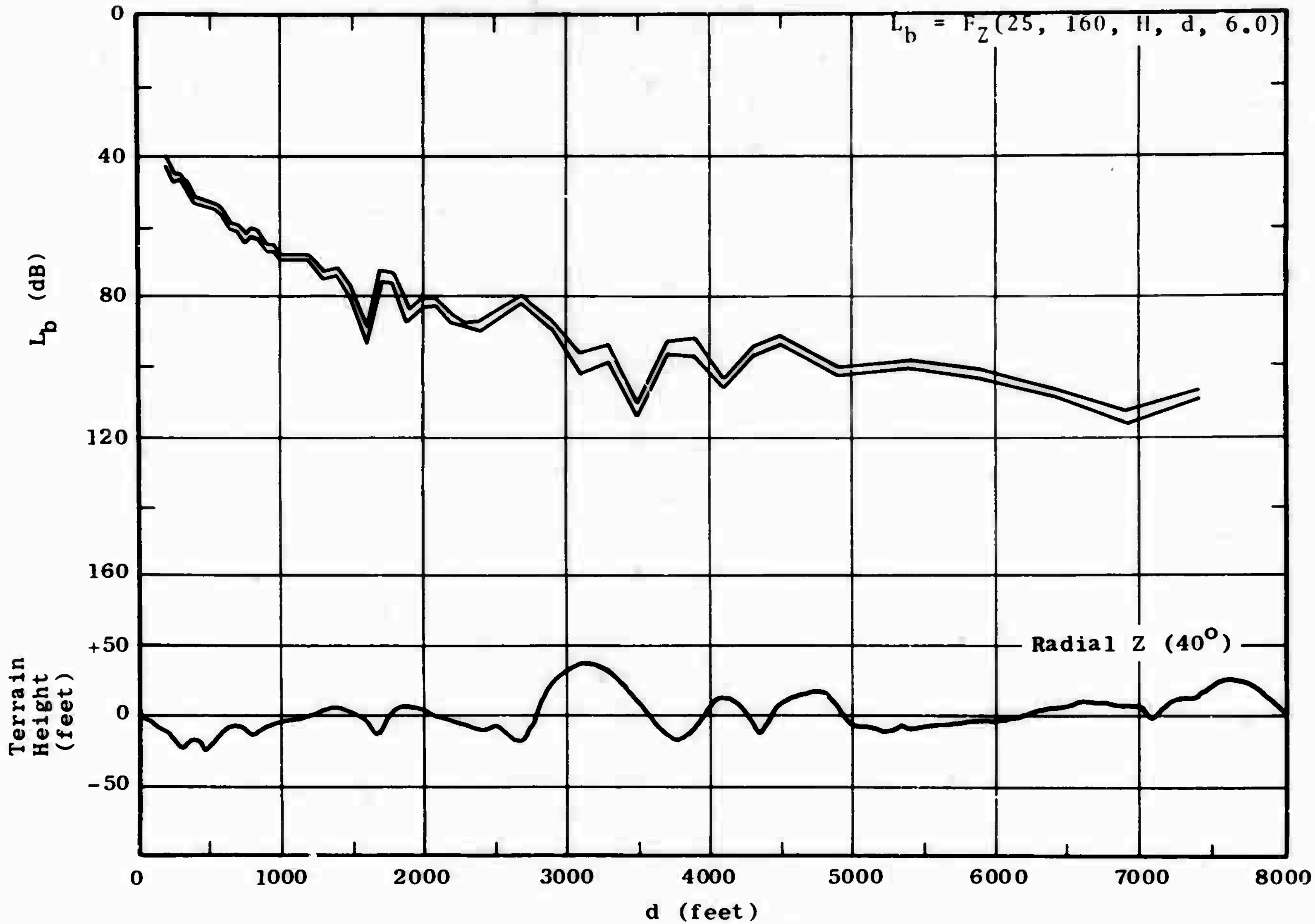


Figure 5.6a Maximum and Minimum Basic Transmission Loss as a Function of Distance

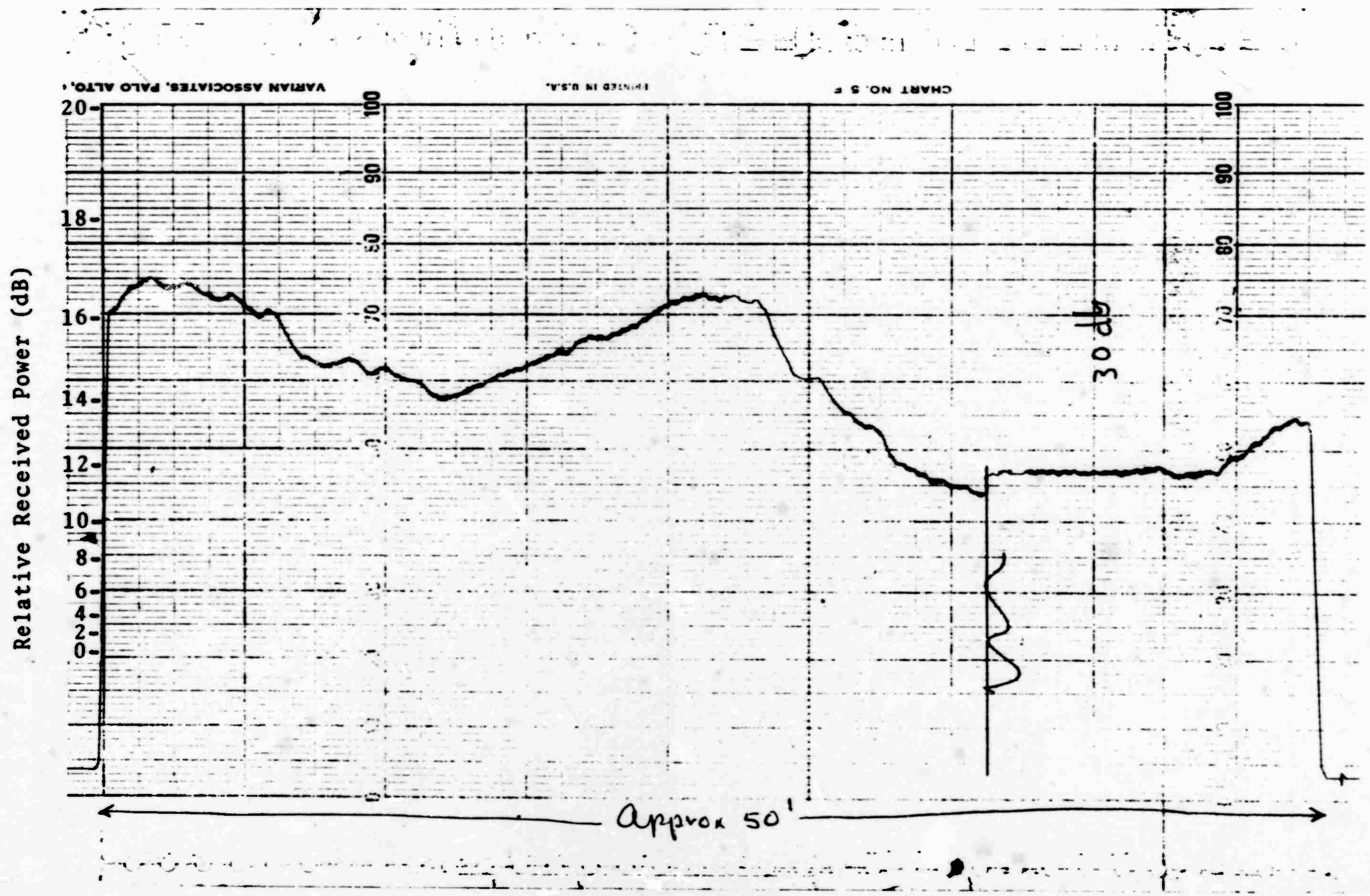


Figure 5.6b Continuous Recording of Received Power Over a 50-Foot Distance
$F_Z(25, 160, H, .473, 6.0)$

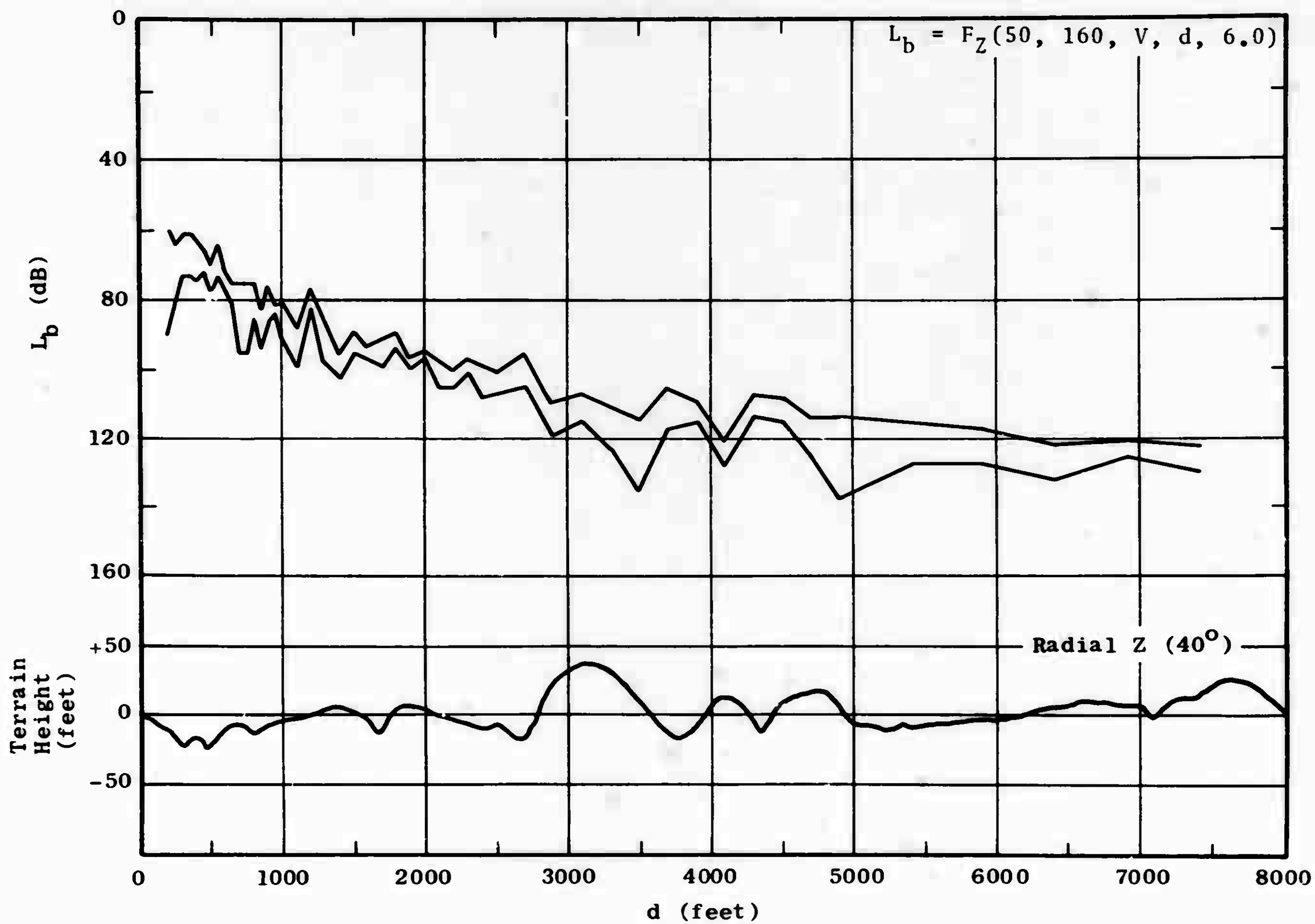


Figure 5.7a Maximum and Minimum Basic Transmission Loss as a Function of Distance

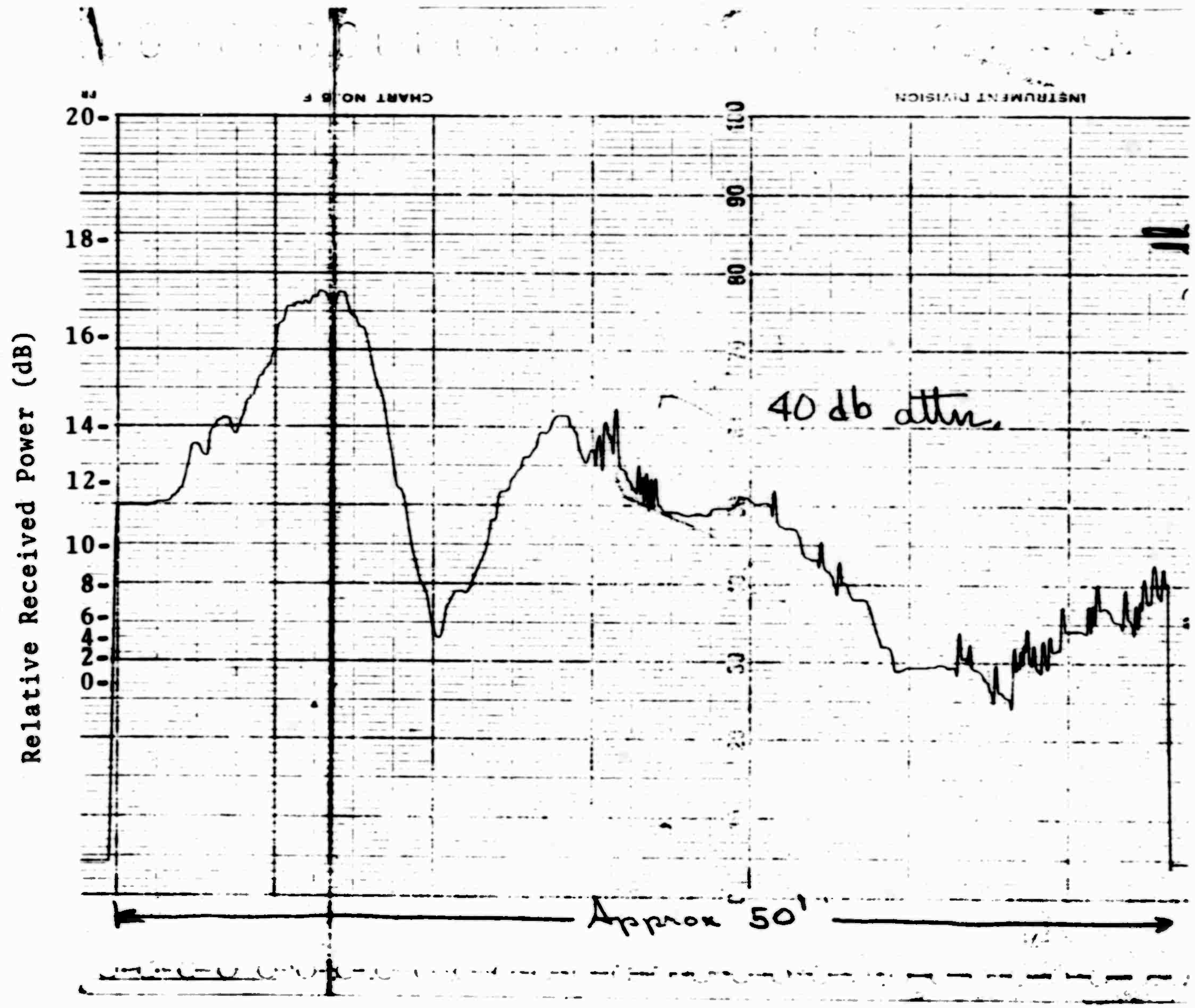


Figure 5.7b Continuous Recording of Received Power Over a 50-Foot Distance
$F_Z(50, 160, V, .473, 6.0)$

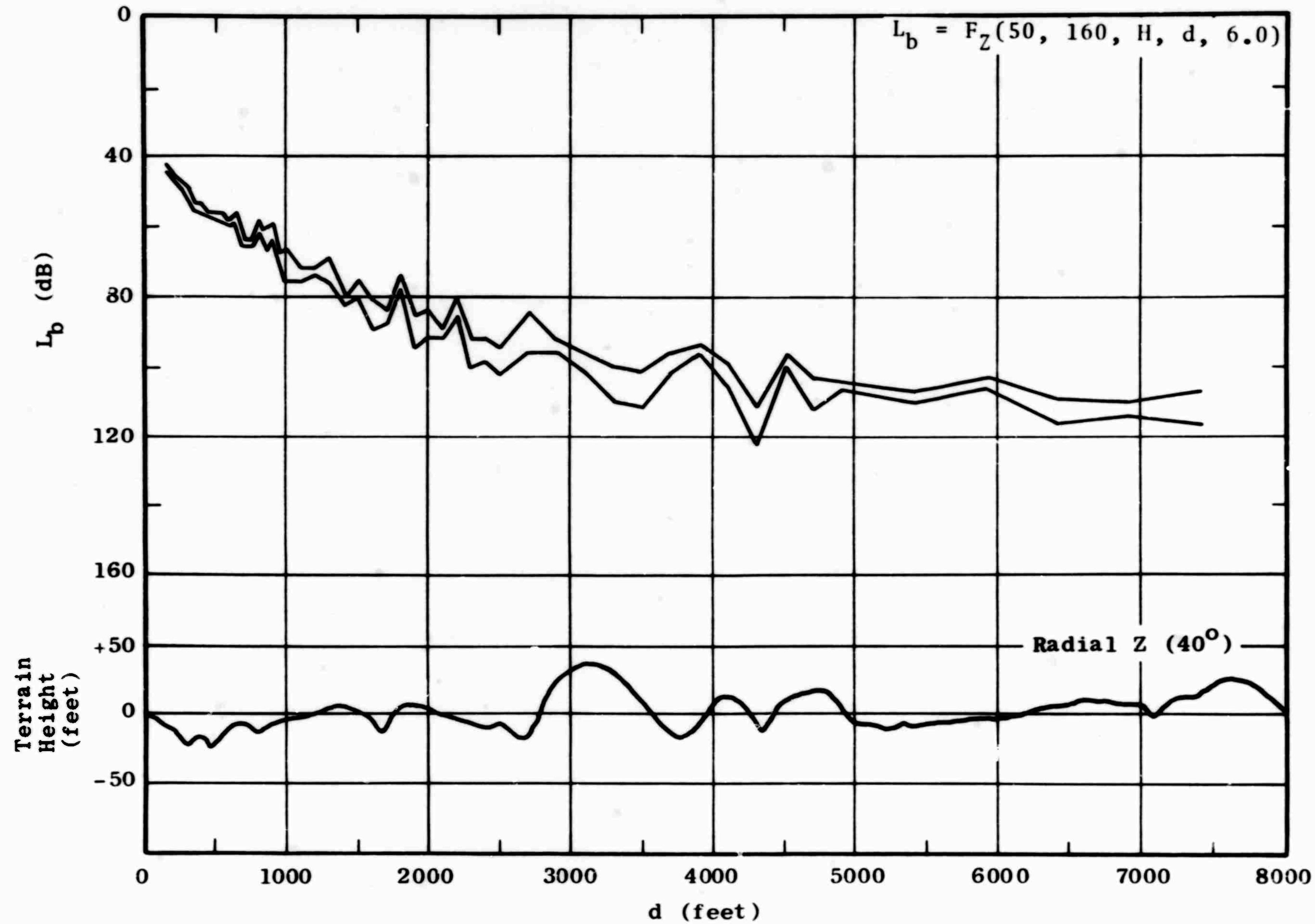


Figure 5.8a Maximum and Minimum Basic Transmission Loss as a Function of Distance

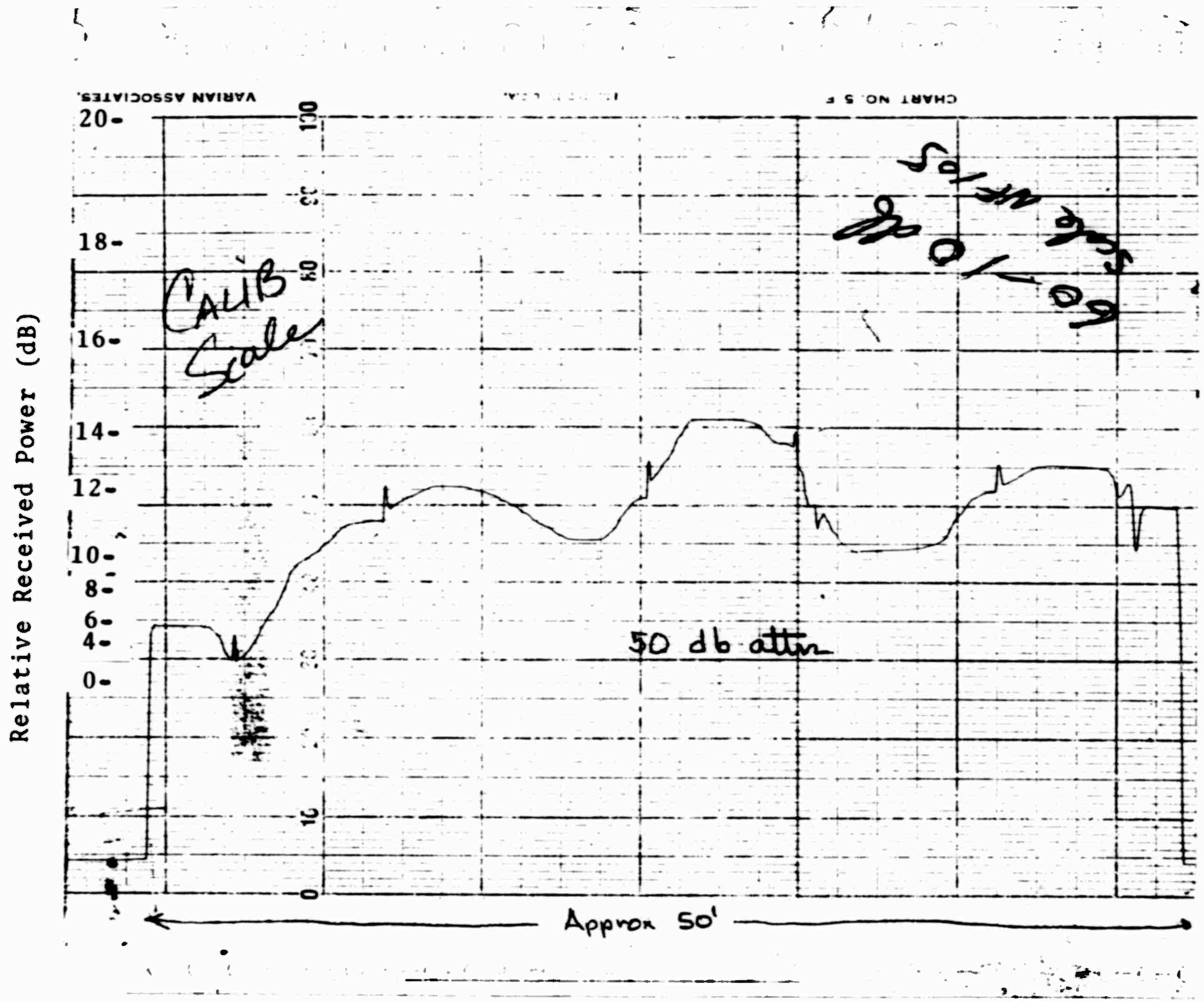


Figure 5.8b Continuous Recording of Received Power Over a 50-Foot Distance
$F_Z(50, 160, H, .473, 6.0)$

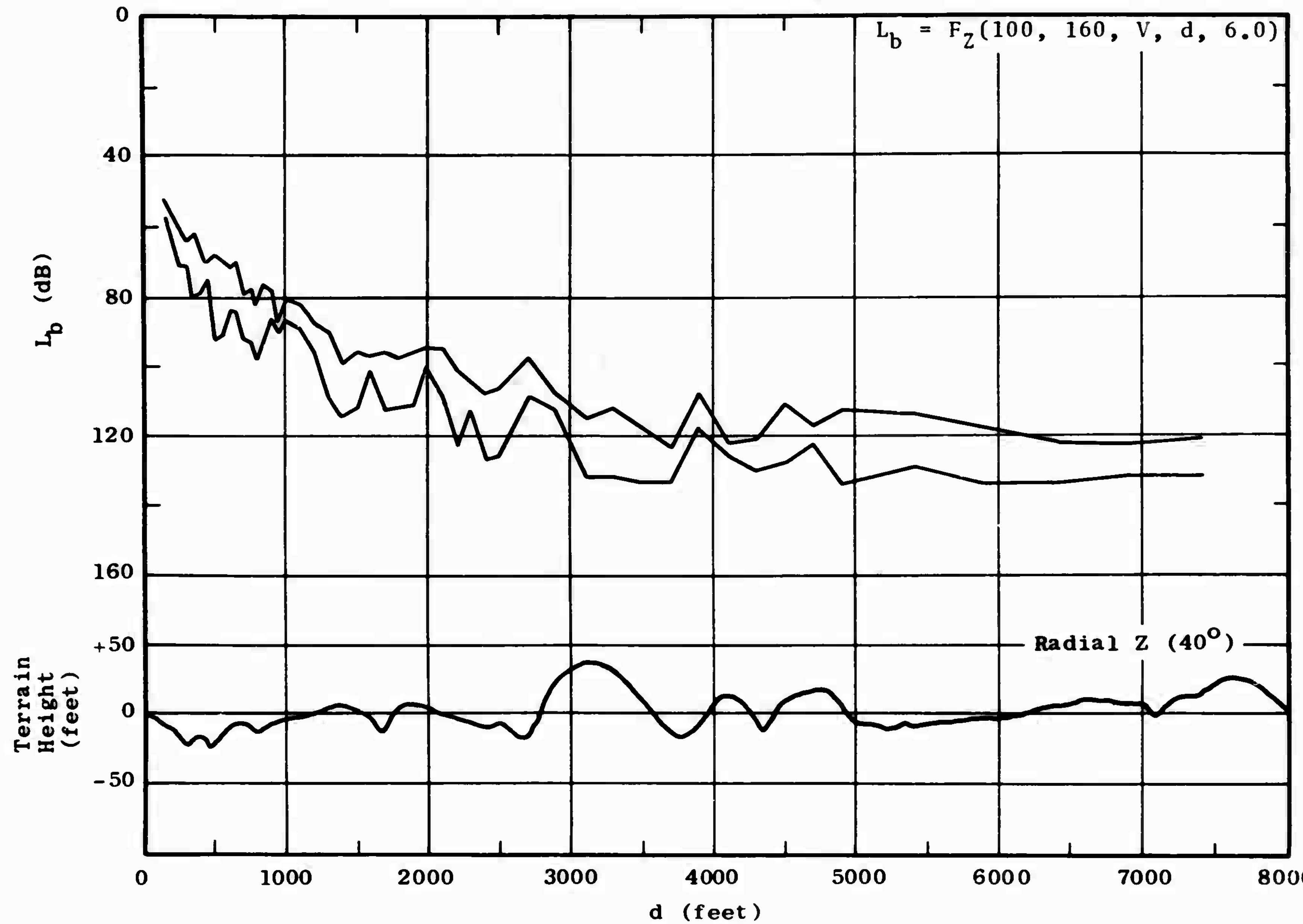


Figure 5.9a Maximum and Minimum Basic Transmission Loss as a Function of Distance

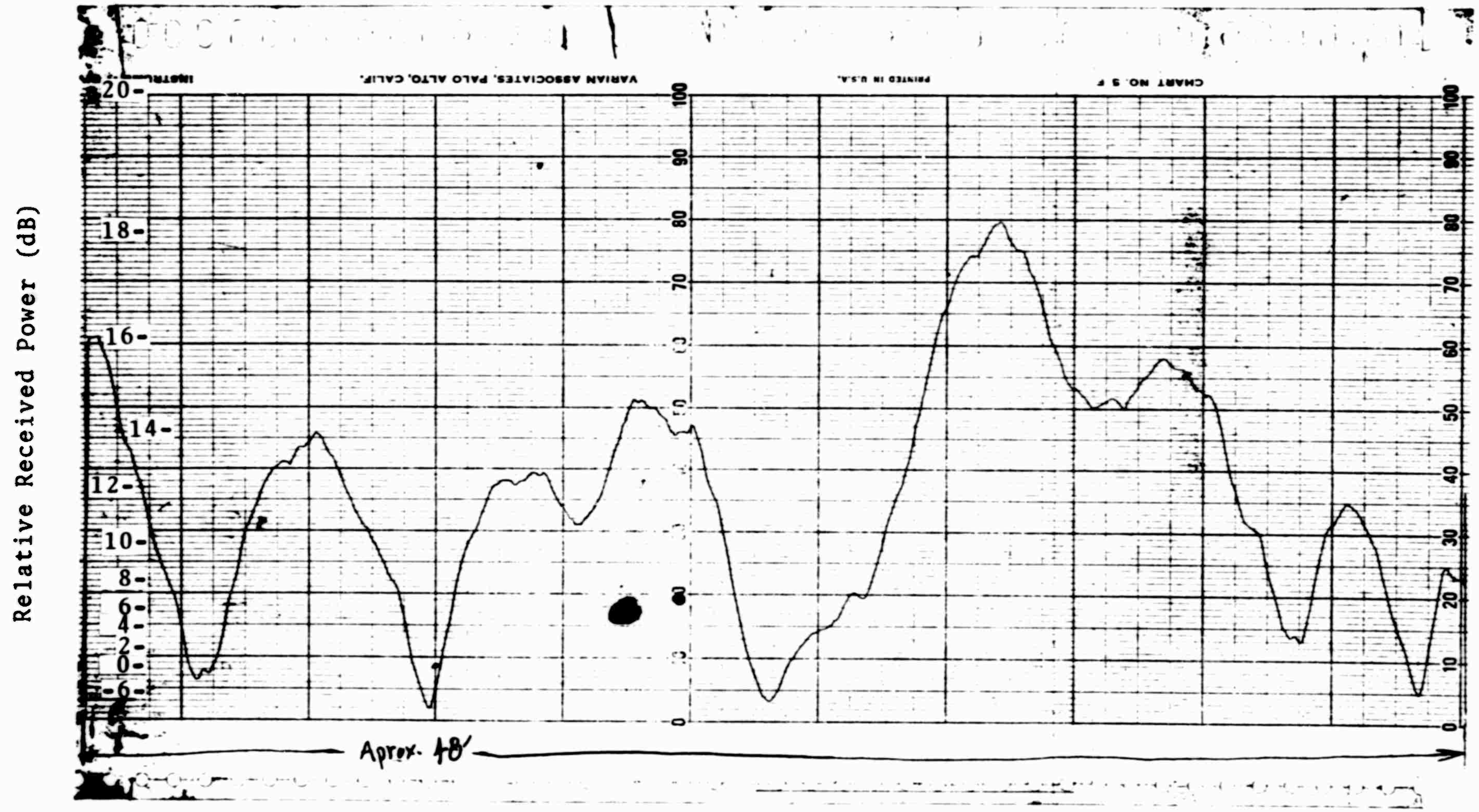


Figure 5.9b Continuous Recording of Received Power Over a 50-Foot Distance
F_Z(100, 160, V, .473, 6.0)

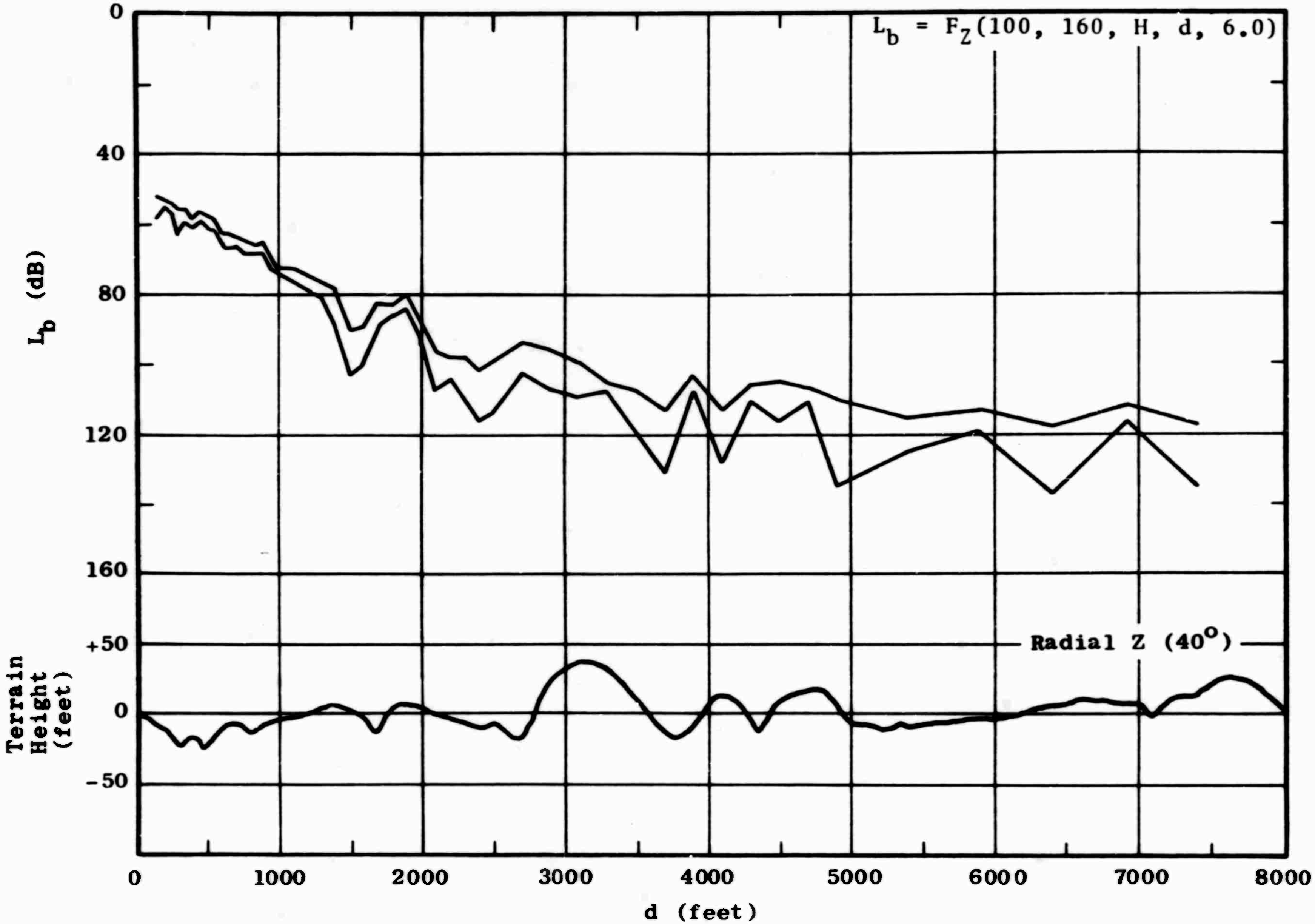


Figure 5.10a Maximum and Minimum Basic Transmission Loss as a Function of Distance

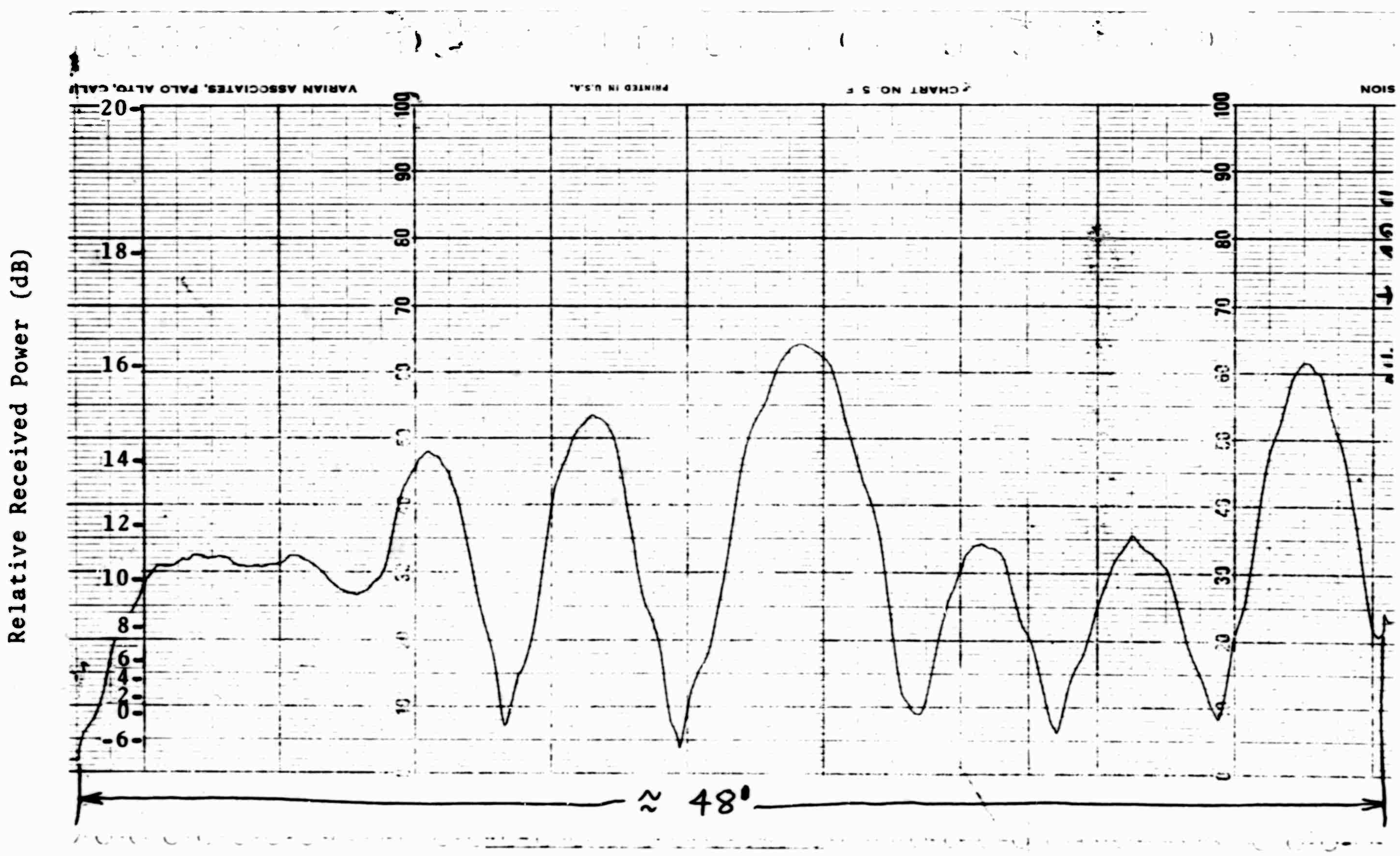


Figure 5.10b Continuous Recording of Received Power Over a 50-Foot Distance
$F_Z(100, 160, H, .473, 6.0)$

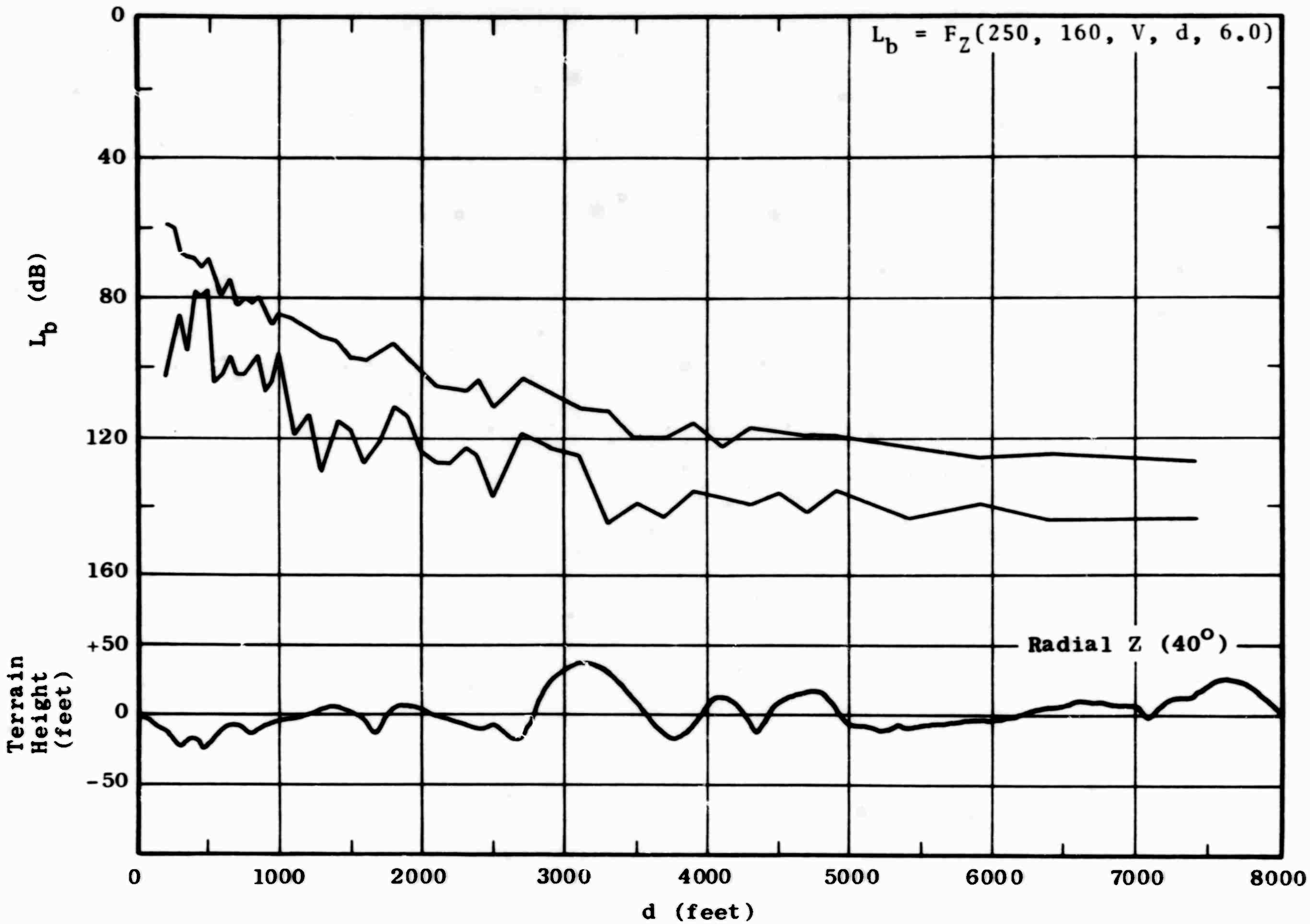


Figure 5.11a Maximum and Minimum Basic Transmission Loss as a Function of Distance

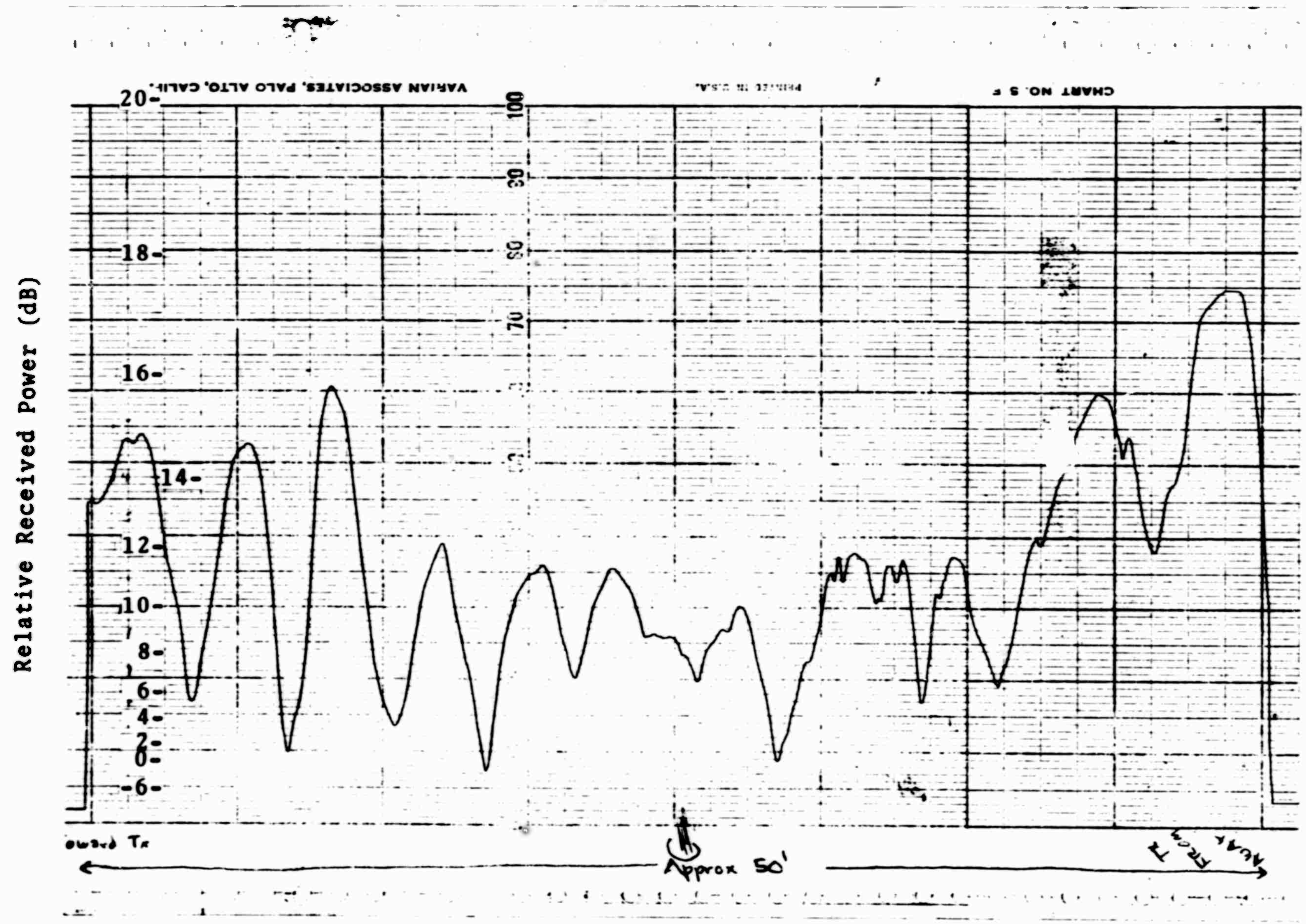


Figure 5.11b Continuous Recording of Received Power Over a 50-Foot Distance
$F_Z(250, 160, V, .473, 6.0)$

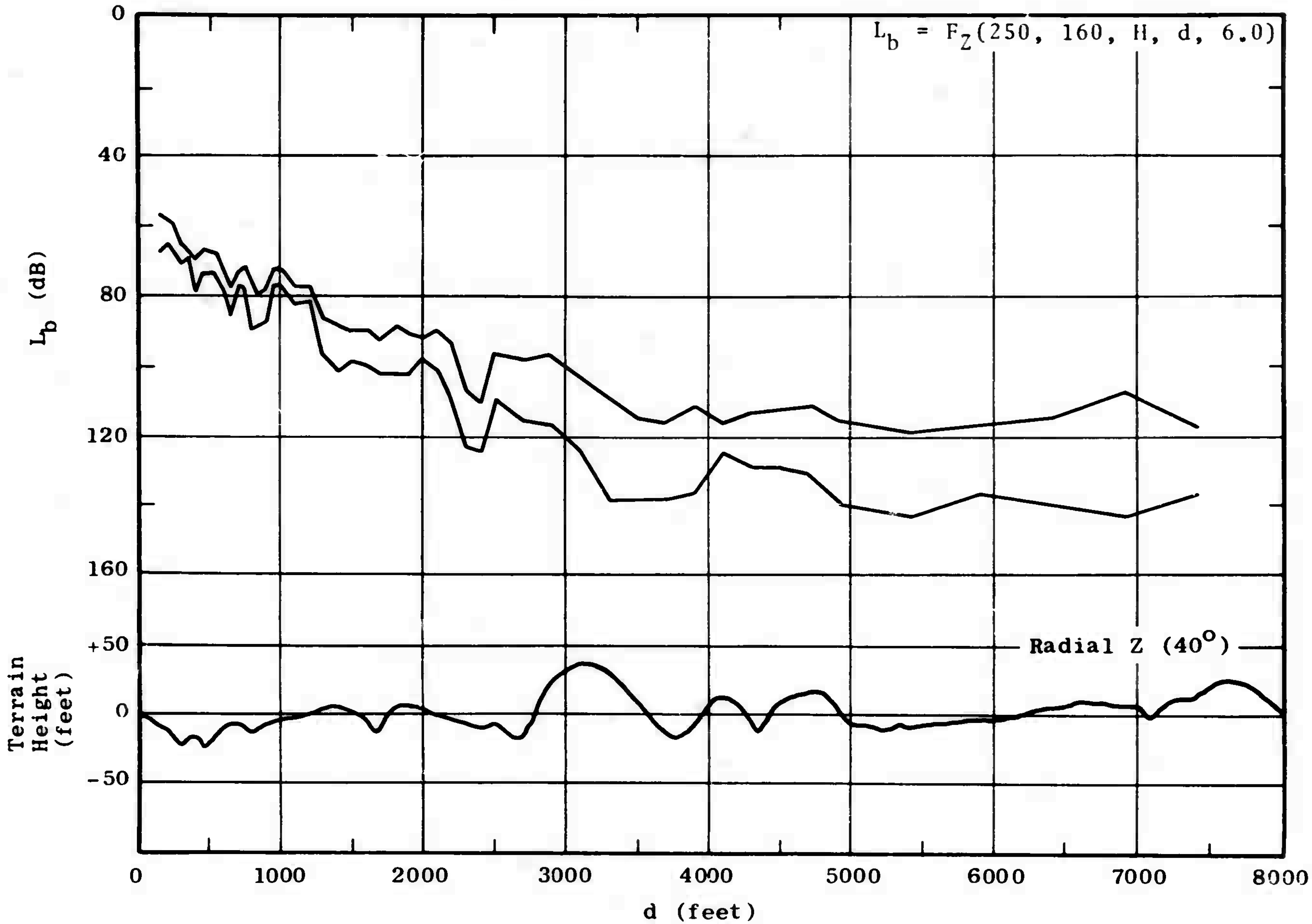


Figure 5.12a Maximum and Minimum Basic Transmission Loss as a Function of Distance

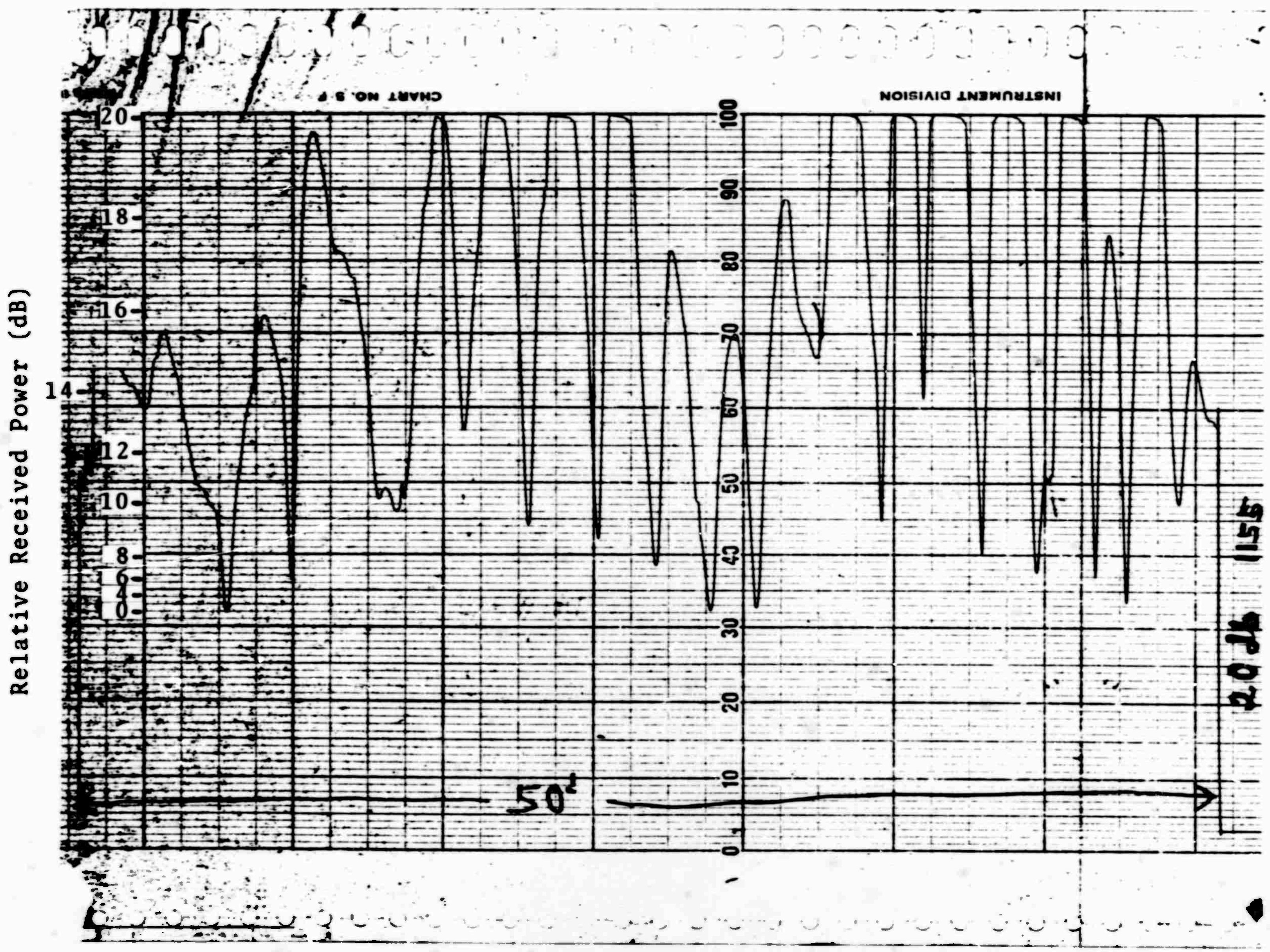


Figure 5.12b Continuous Recording of Received Power Over a 50-Foot Distance
$F_Z(250,\ 160,\ H,\ .473,\ 6.0)$

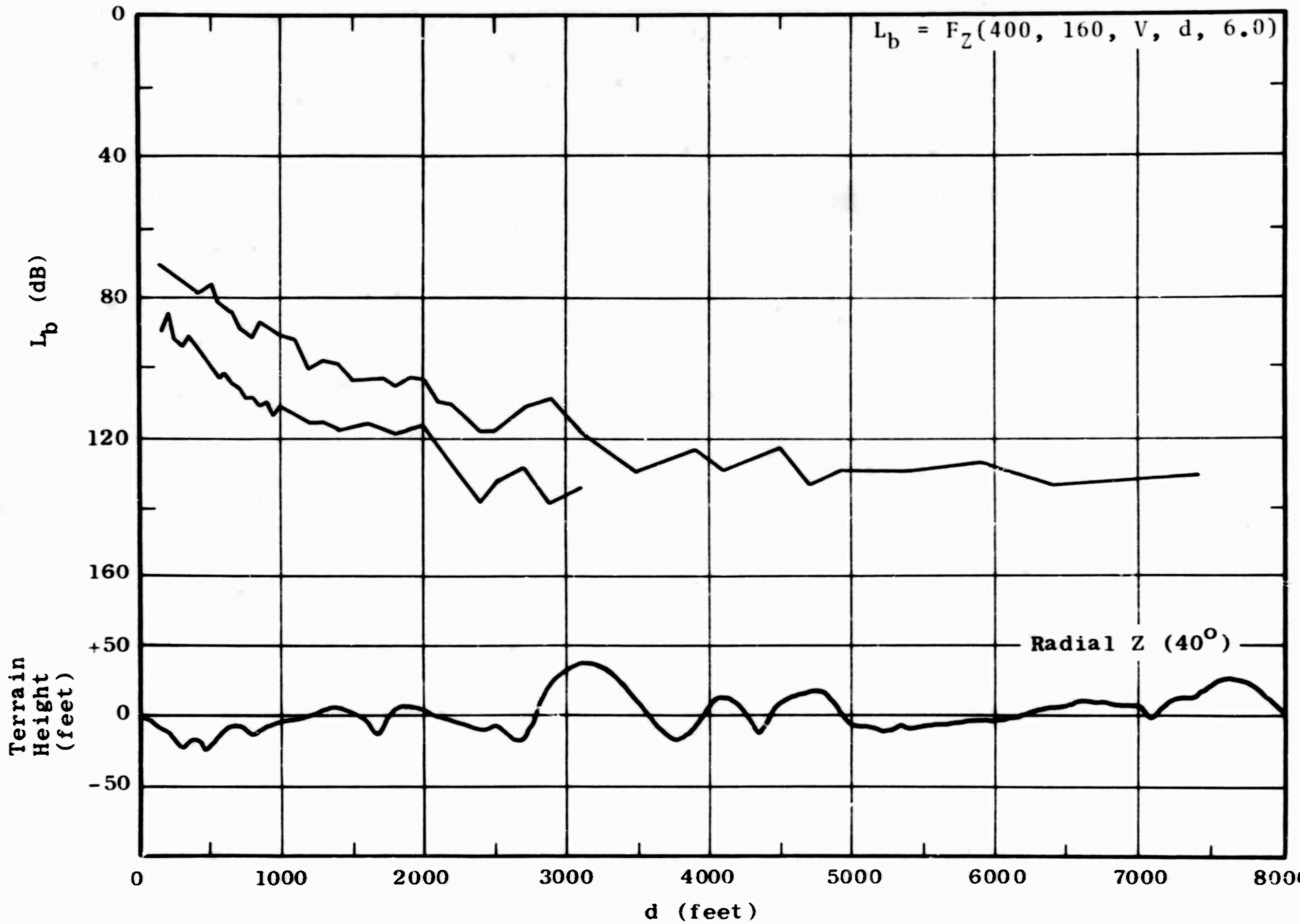


Figure 5.13a Maximum and Minimum Basic Transmission Loss as a Function of Distance

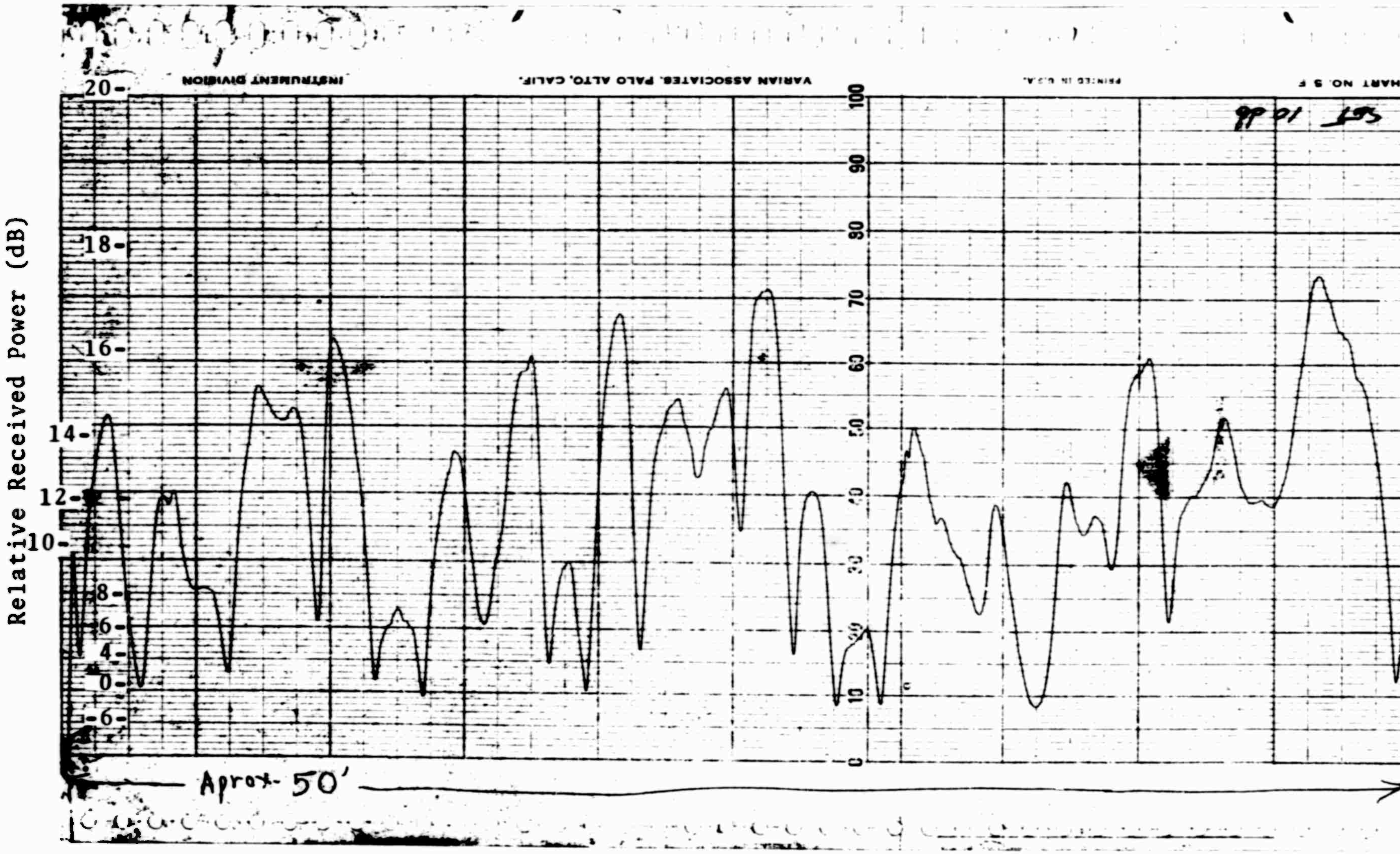


Figure 5.13b Continuous Recording of Received Power Over a 50-Foot Distance
$F_Z(400, 160, V, .473, 6.0)$

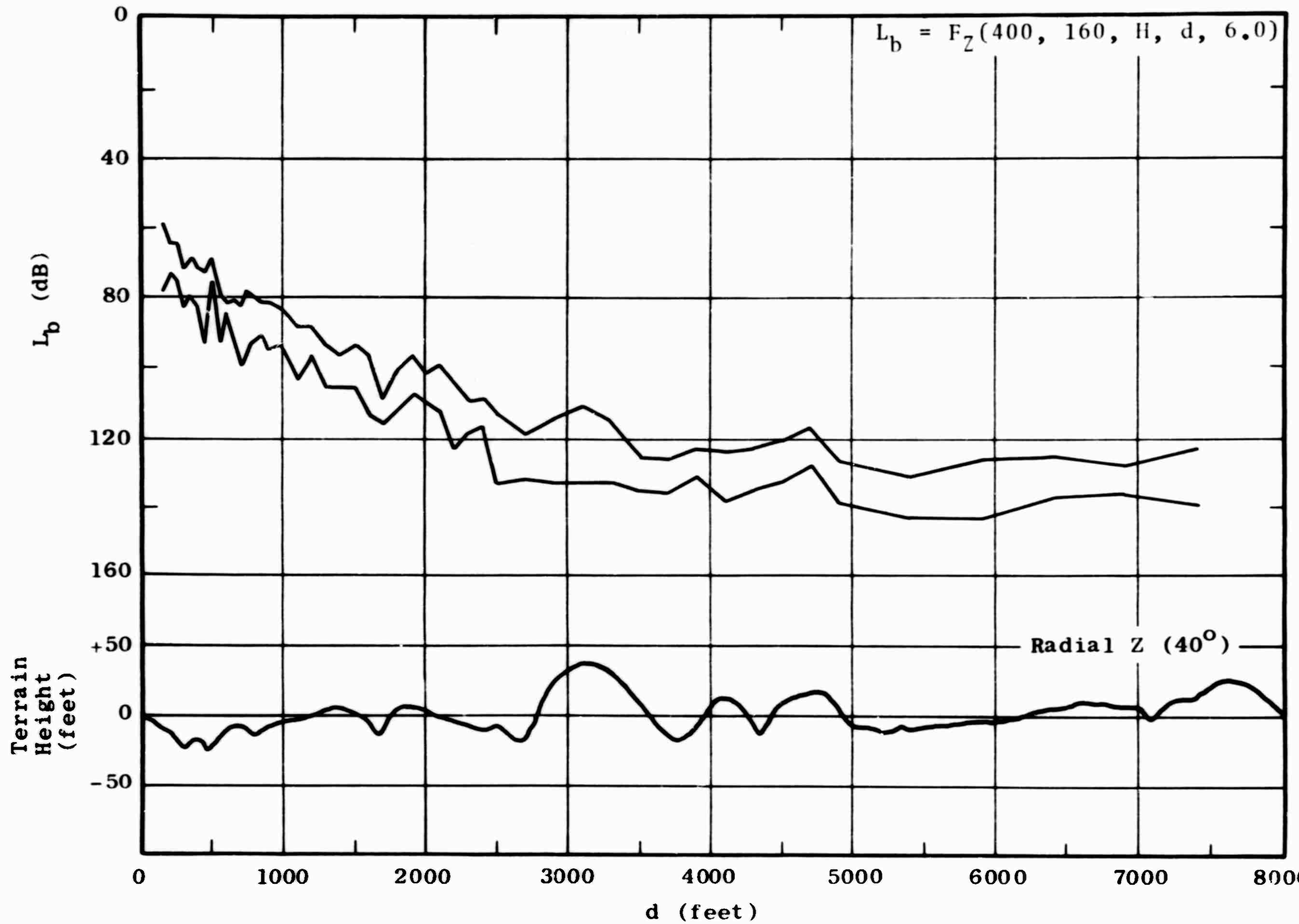


Figure 5.14a Maximum and Minimum Basic Transmission Loss as a Function of Distance

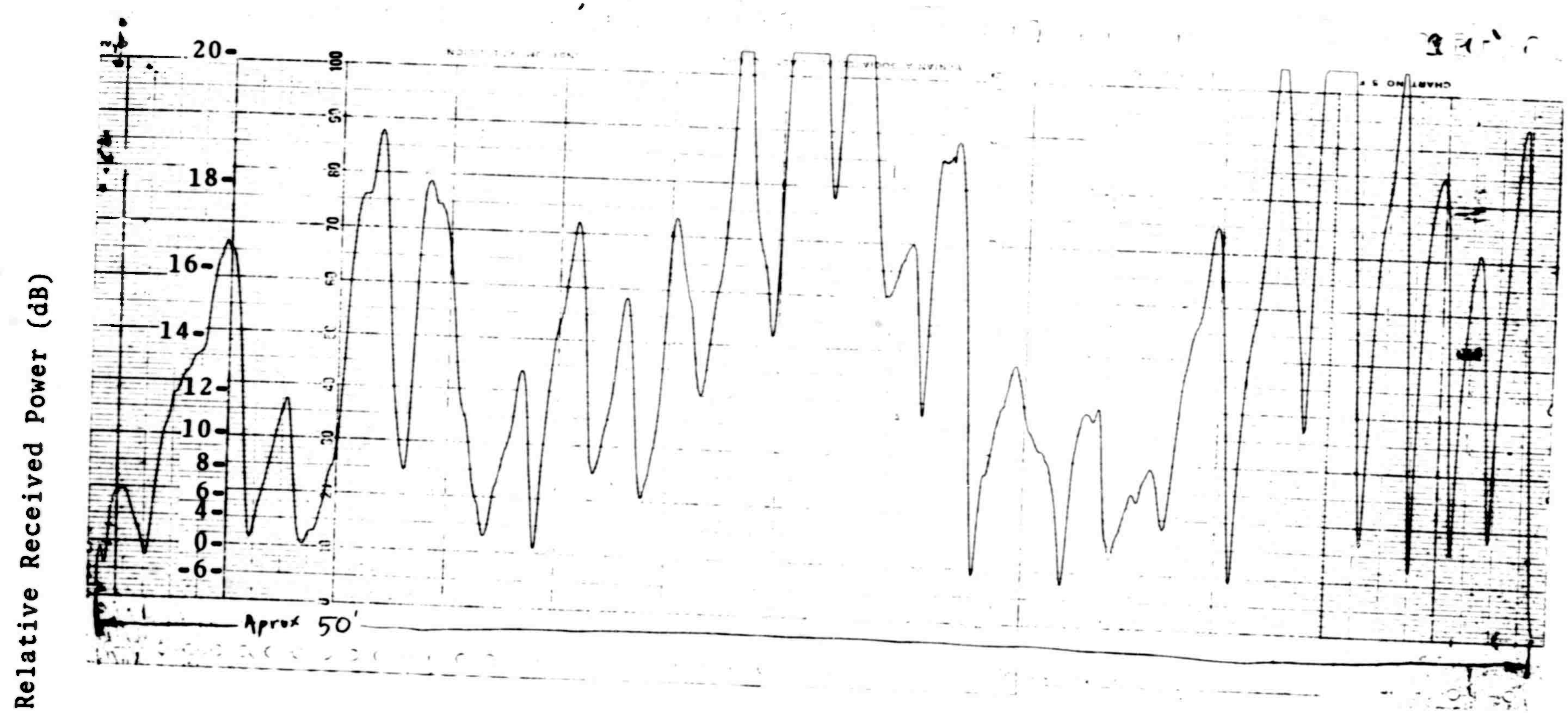


Figure 5.14b Continuous Recording of Received Power Over a 50-Foot Distance $F_Z(400, 160, H, .473, 6.0)$

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6. CLIMATOLOGICAL TESTS

The climatological measurements at the Area II test site included the daily temperatures, humidities, and rainfall. In general, the measurements were conducted three times a day during the following hourly intervals: 700-900, 1100-1300, and 1500-1700. The measurement location was within the base camp area, which is 130 feet above sea level and has coordinates of 7°00′N latitude and 99°53′ E longitude.

Since the technical personnel were not at the site every day, the three sets of daily measurements were conducted on about 60 percent of the days in 1967. This sampling rate is high enough to obtain accurate monthly averages. The rainfall measurements were not affected by the intermittent sampling because the guage was an automatic device that could continuously run unattended for seven days.

Figure 6.1 illustrates monthly rainfall accumulation and the average monthly temperatures, relative humidities and refractive indices (K values). Except for the rainfall data, the basis for the average values was wet and dry bulb readings taken during the three measurement intervals. From these values were calculated the relative humidity and refractive index. Then, all the measured dry bulb temperatures, and calculated humidities and refractive indices were averaged over each month.

Tests at different areas of Thailand and in different seasons have indicated that the climate does not directly induce significant changes in path loss. However, climate indirectly has a very substantial effect on path loss through its influence on vegetative growth.

It is estimated that Area II has about 310 tons of vegetation per acre compared to an estimated 130 tons per acre in Area I. The differences in foliage height and density between the areas show up in path loss comparisons. Since the average humidities and temperatures at the areas are similar, it appears that rainfall accumulation primarily accounts for the different foliage masses.

Figure 6.2 compares the yearly rainfall accumulation for Areas I and II. The Area II accumulation represents measurements made during 1967 only, and the Area I accumulation is an average value from measurements made there between 1964 and 1966.

In order to determine if the rainfall data from Area II during 1967 was representative of normal conditions, the average rainfall for that region over a 22-year period was also plotted. This 22-year average was obtained from the Thai government and agrees well with 1967 Area II data.

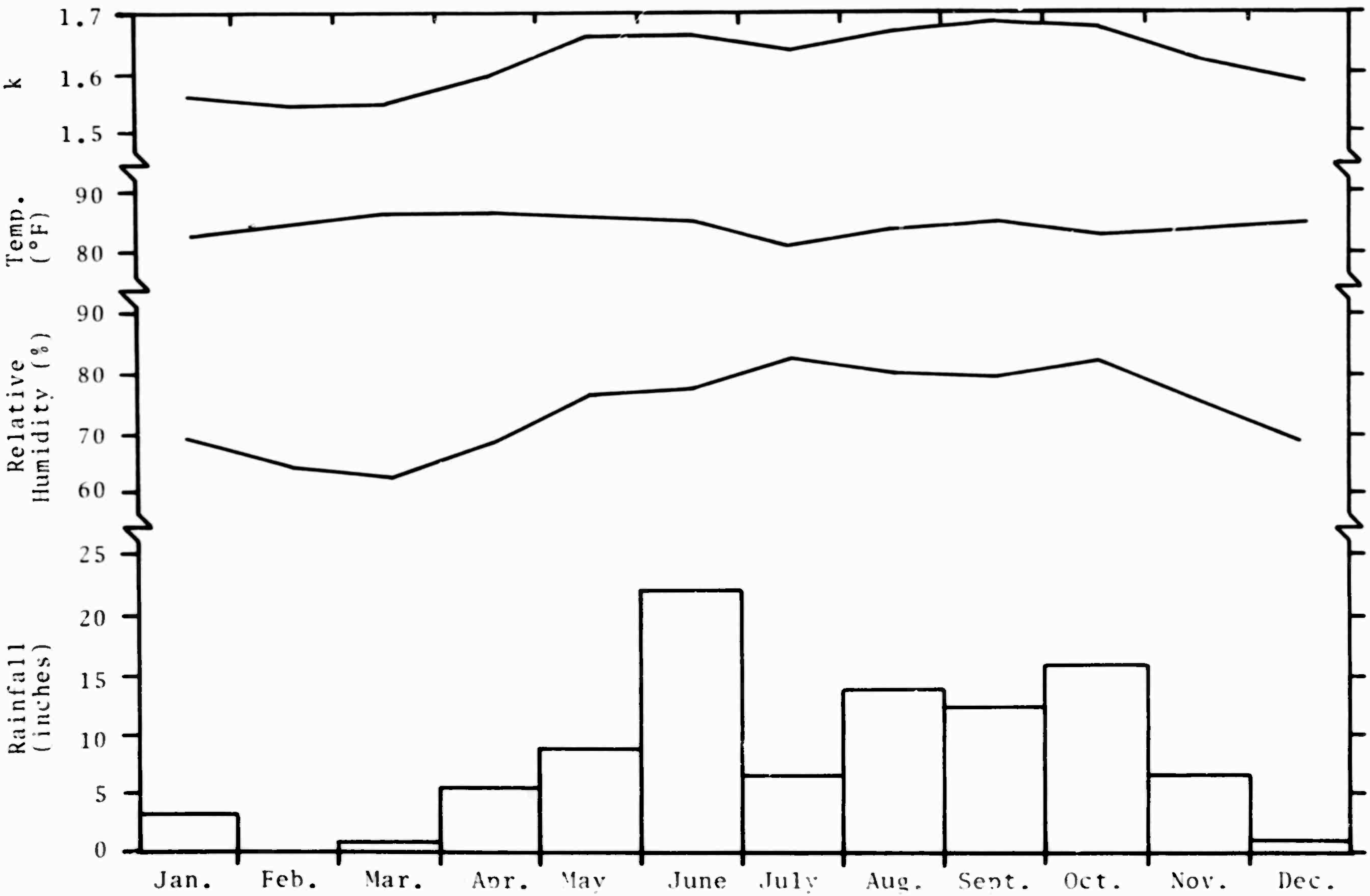

Figure 6.1 Monthly Climatological Parameters at Area II Test Site in 1967

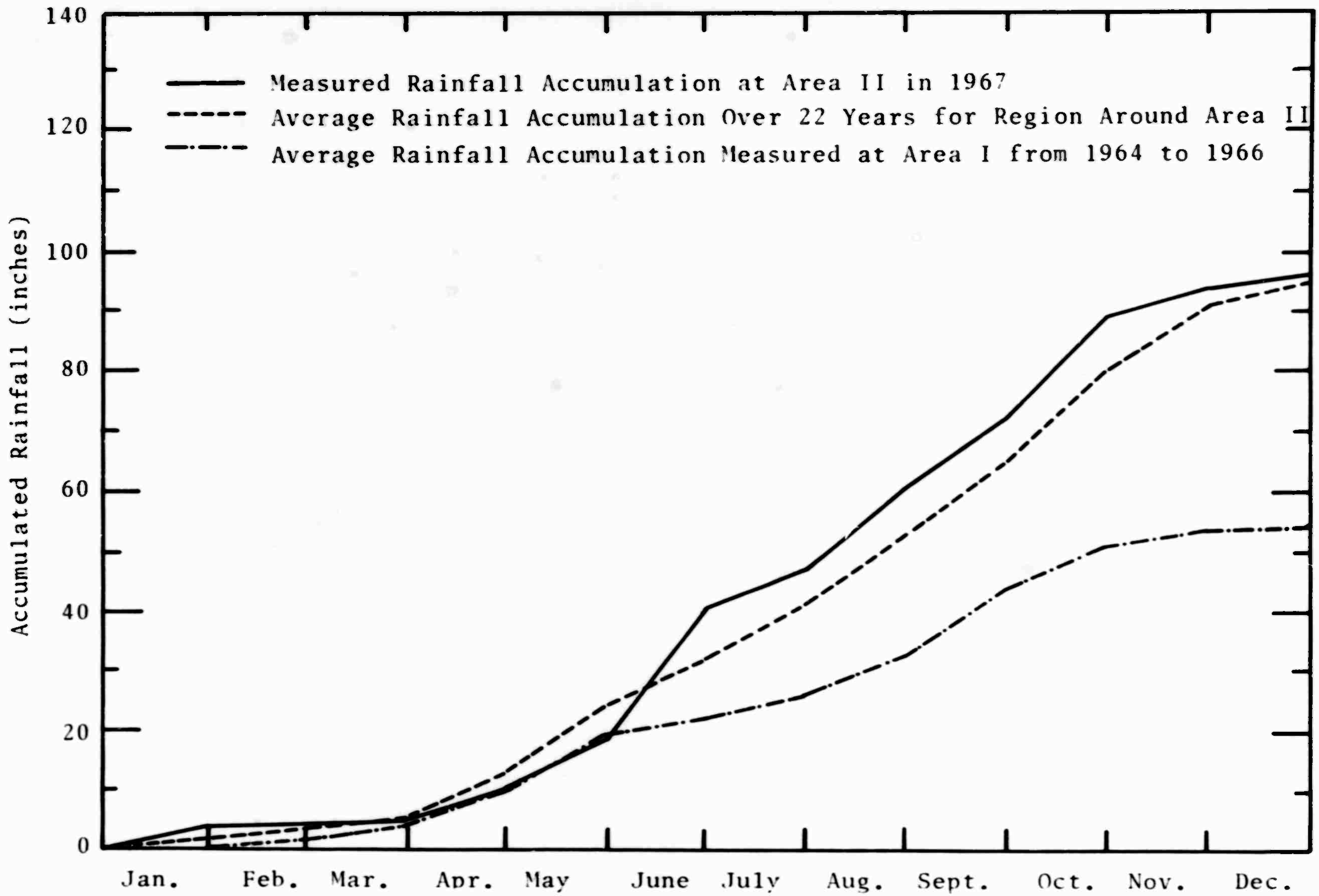

Figure 6.2 Annual Rainfall Accumulation for Thailand Test Areas

7. REFERENCES

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2. Op. Cit., Sections 2, 6.4.

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8. Tropical Propagation Research, Jansky & Bailey Engineering Department of Atlantic Research Corporation, Final Report Volume I, Contract No. DA 36-039 SC-90889, DDC No. AD 660-318, Section 5.9.2.4.

9. Op. Cit., Sections 6.6.1, 6.6.2.

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The following individuals have made significant contributions to the work accomplished during this report period.

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13 ABSTRACT

Semiannual Report Number 10 of the Tropical Propagation Research Project contains the results of measurements and analyses done between 30 June and 31 December 1967. The measurements were conducted in a thick rain forest located approximately half-way between the towns of Songkhla and Satun on the southern peninsula of Thailand. Five different sets of data are covered herein: (1) path losses for frequencies from 880 kc/s to 250 Mc/s at 0.1-6.0-mile transmission distances, with antennas located from 0 to 120 feet above ground; (2) path losses for frequencies from 25-250 Mc/s at 0.05-1.5-mile distances. Transmitting antennas vary from ground level to 120-foot elevations, and receiving antennas were at various heights and orientations within 10 feet of the ground. (3) Path losses and foliage attenuation rates for 0.55-10 Gc/s frequencies over 300-foot transmission paths and at antenna elevations from 9 to 99 feet; (4) path losses for 25-400 Mc/s frequencies at distances from 0.01 to 1.5 miles, using 160-foot-high transmitting antennas and 6-foot-high receiving antennas; (5) temperature, rainfall, and humidity data for the period covered by this report. Except for the 880-kc/s transmissions, all tests were conducted at both polarizations. In certain tests, the data has been averaged, or otherwise reduced, and compared with different data from equivalent tests.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Techniques						
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SEA - Southeast Asia						
Thailand						
Path Loss						
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